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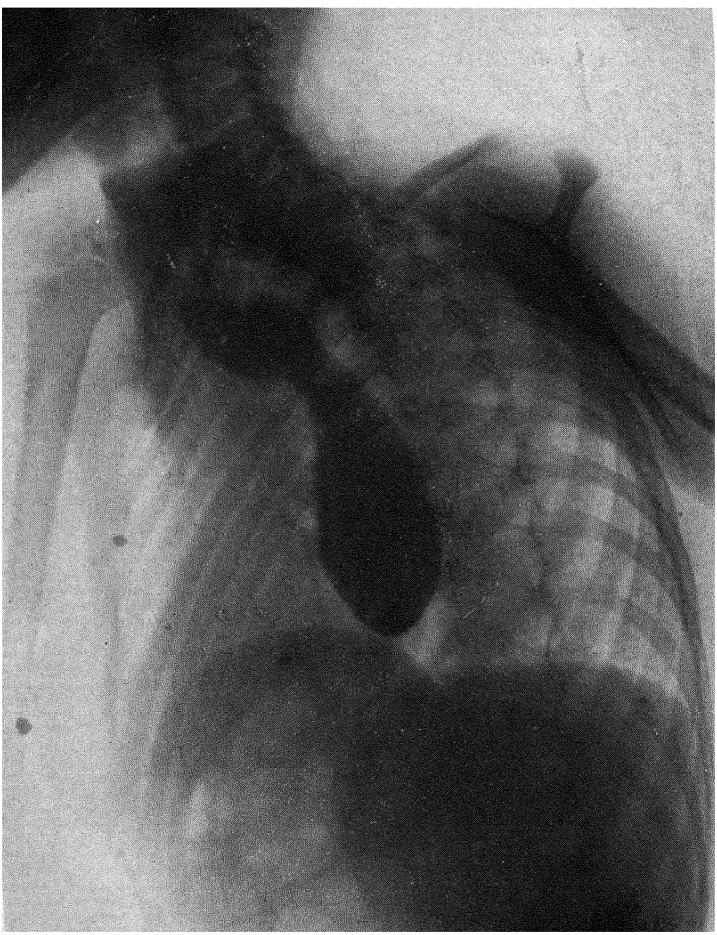
RADIOGRAPHIC TECHNIQUE



Complete stricture of the œsophagus, in boy 4¼ years old.
Half-second exposure.

(Reproduced by courtesy of the Imperial Dry Plate Co., Ltd.)

Frontispiece.

RADIOGRAPHIC TECHNIQUE

BY

T. THORNE BAKER, A.M.I.E.E.

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PREFACE

THIS book has been written with the object of placing before the reader, be he operator or expert, the various details of photographic technique of which a knowledge is so necessary in radiographic practice. The number of works dealing with X-ray grows apace, but they one and all deal with the more or less general practice of radiology, and in many cases the treatment of the purely photographic side has been rather neglected. Just as many people ignorant of pure photography think that the possession of a good camera or a fine lens will secure the production of excellent photographs, so the radiologist is often led to imagine that high power installations and lavish equipment must lead to the best radiographic results. The photographic knowledge of many operators is lamentably inefficient, the busy medical man has little time to study photographic principles; yet a knowledge of the principles underlying the production of technically good negatives and prints is indispensable in order

successfully to operate X-ray installations, large or small.

A preliminary chapter has been given which deals with the installation itself, in order to aid the operator in locating faults or breakdowns; but the chief aim of the author has been throughout to put together in concise form the photographic and other information so essential to the operator or radiologist who requires the best photographic results under varying or difficult conditions, which, as already stated, has been more or less omitted from other text-books.

Radiography is a somewhat intricate mixture of medical science, electricity, and photography, all of which must be co-ordinated if satisfactory work is to be done. The many practical points in connection with the intelligent use of intensifier screens, the control of the photographic image in exposure and development, the management and equipment of the dark-room, and so on, are fully discussed, and two concluding chapters have been added which deal with some of the recent industrial applications of radiography, which not only greatly enlarge the future scope of this comparatively new science, but open up possible occupation for some of the many operators whose

services were engaged during the war for military work.

I take this opportunity of expressing my thanks to Messrs. Watsons (Electro-Medical), Ltd., who have helped me considerably with information and illustrations of apparatus, and to my wife, whose assistance in my laboratory in preparing much of the matter has been invaluable.

1 Brondesbury Mansions, N.W. 6.

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CHAPTER I

The scope of X-ray work—Importance of photographic technique in radiography—Modern apparatus—Sources of power—Resistances and switchboards—Fault location.

It is not usually recognised by those engaged in radiographic work that photography with the X-rays is primarily a photographic operation; that radiography is a three-fold science, requiring a knowledge of photography and electricity as well as of medicine. The chief object of the radiograph is to provide the medical man with a means of diagnosis, but this means is only satisfactory when the photographic character of the radiograph is good.

Much of the value of an X-ray installation may be lost if the necessary photographic knowledge and operating technique be lacking; a radiographer may equip himself with a very powerful installation, and all kinds of elaborate appliances, and then be disappointed that he can do no better than another with a far humbler equipment. The latter is probably handled by a man who is thoroughly acquainted with the practical side of the work—who can produce far better photographic results, and can obtain the most perfect

combination between the electrical and photographic conditions involved.

Radiology plays such an important part in modern medicine that in most hospitals one or more operators are employed to do the purely technical work, but they too frequently find that it is not to be conducted on ordinary photographic lines; many medical men—and the number is growing greater daily—have a moderate-sized installation of their own and do the whole of the work themselves.

The object of this book is to provide practical information for both, and to omit matters that have been so often and so ably treated in the text-books on X-ray work which have been written by medical men. It will also be assumed that the rudimentary principles of electricity are known, or can be assimilated from one of the many elementary text-books available.

X-rays are produced by the excitation of the highly exhausted X-ray tube by a high tension (high voltage) current generated by means of an induction coil or high tension transformer. In selecting a coil and its auxiliaries the nature of the current available must be considered. The voltage usually given by electricity supplies is 100, 200 or 240, and this may be uni-directional or alternating. The former—direct current—is necessary for induction coils, the latter for transformers. Direct current is also necessary for

charging accumulators or storage batteries. The primary current obtained from any such sources must be transformed up to a voltage of some tens, or even hundreds, of thousands in order to overcome the resistance of an X-ray tube. While modern progress tends to indicate that the high tension transformer will be almost universally employed for large installations in the future, the induction coil is far more commonly employed at present, and any coil capable of giving a ten-inch spark in air, and upwards, can be employed in X-ray work.

There are a good many different types of coil available, but all work essentially on the same principles. The induction coil consists essentially of a central soft iron wire or laminated iron core, over which is a *primary* winding of one or two layers of fairly thick insulated copper wire. The primary winding is then covered with a heavy tube of ebonite or mica, in order to insulate it very heavily from the *secondary* winding. The latter is wound over the insulating tube, and may consist of several miles of very fine insulated copper wire, of No. 36 or No. 38 gauge. The increase in voltage depends on the ratio of the number of turns on the secondary to the number of turns on the primary.

The secondary coil is wound in sections for the purpose of better insulation; the winding is carried out in various ways by different makers,

but each section is usually so impregnated in paraffin wax that wax really forms the insulating material. When a coil breaks down, it may be due to the fact that sparking has occurred at some part of the winding, and has caused either a breakdown of the insulating material or an actual burning through or rupture of the wire. It is then the instrument maker's business to test each section of the winding, locate the fault, and repair it. Provided due care be exercised in the operating of an X-ray installation there should be little fear of a breakdown. Instrument makers, however, sometimes complain that an urgent call is made for an expert to be sent perhaps a long railway journey, in order to put right an installation which 'will not work,' and it is found on investigation that the whole trouble is a faulty or loose connection on the switchboard. Little faults of this kind ought to be capable of detection by every one who uses an X-ray apparatus, and in order to give a general idea of the various parts to be looked over in case of trouble a very brief description will be given in this chapter of component parts of the coil, interrupter, resistances, switchboard and so on.

In selecting a coil, it must be borne in mind that the primary can be wound to suit the electricity supply, or the voltage of the supply can be controlled by means of resistances, the latter being the usual course. Coils are generally made suitable

for running from anything between a storage battery giving 24 volts to a direct supply at 250 volts. The primary voltage is of importance, because the secondary voltage depends not only on the ratio of the number of turns in the secondary to the number of turns in the primary, but directly also on the voltage applied to the primary. For this reason storage batteries should only be used if possible for cases where a portable coil has to be taken to a patient's house, as with 24 or 36 volts only a great degree of penetration is not obtainable.

The advantage of a 16-inch coil (*i.e.* a coil giving a 16-inch spark in air), over a 12-inch coil is that the thick parts of the body can be photographed in considerably less time, with the result that a sharper image is obtained. By passing a primary current of 20 to 60 ampères through the primary of a suitably built 16-inch or 20-inch coil, exposures of a hundredth or even a thousandth of a second can be given, with which distinct detail can be obtained in moving parts such as the heart, lungs, etc.

In Fig. 1 the essential parts of the coil winding are shown; *PP* represents the primary winding of one or two layers of thick copper wire wound round the central core of soft iron *AB*. *I* is a heavy mica tube, thickly coated with shellac, over which the secondary winding *SS* is placed. If we disregard an evitable loss in transformation, then a current of 5 ampères at 100 volts passed

through the primary would, on interruption, induce a current of say 5 milliampères (five thousandths of an ampère) at a voltage of 100,000—the product of the volts×ampères being the same in each case. In practice, a good deal of the primary energy is lost in the transformation, but in a well-constructed coil it need not be more than 30 per cent.

The primary is usually divided and an arrangement of terminals of its sections given, so that by connecting up in different ways the two layers in the coil can be placed in parallel or series. It will be remembered that the current passing through any circuit increases directly as the voltage or inversely as the resistance, so that if we have the two layers of the primary winding in parallel, the resistance will be half that in the case of the two layers being connected in *series*. This arrangement is an advantage, as the series connection can be used in work from accumulators or a low voltage supply.

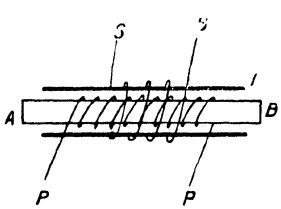


FIG. 1.

The amount of current passing through the primary of the induction coil can be controlled by means of a resistance. In Fig. 2 *P* represents the primary of the coil, and *R* the regulating resistance, consisting usually of a coil of resistance wire capable of carrying several ampères current wound

over a frame and provided with a sliding contact C or a number of studs by which the number of turns of the resistance used can be varied. This resistance is in parallel with the primary of the coil, an arrangement not often used. In Fig. 3 the regulating resistance R is placed in series with the primary.

In the arrangement shown in Fig. 2 the current from the main distributes itself between the

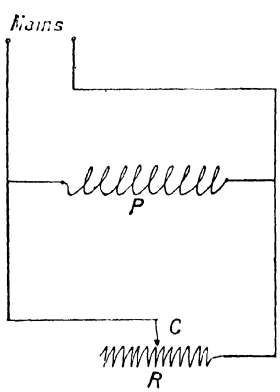


Fig. 2.

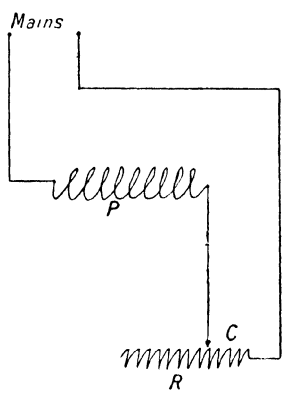


Fig. 3.

primary P of the coil and the regulating resistance, that passing through the coil increasing as the resistance in R is increased, and *vice versa*. From a supply such as one hundred volts or more a second resistance would have to be employed in series with one of the mains terminals and one end of the primary P. In Fig. 3 the primary of the coil and the regulating resistance are connected in series, that is to say, the resistance

of the resistance coil is added on to the resistance of the primary, so that as R is increased less current passes through P and as it is decreased more current passes through P. These resistance

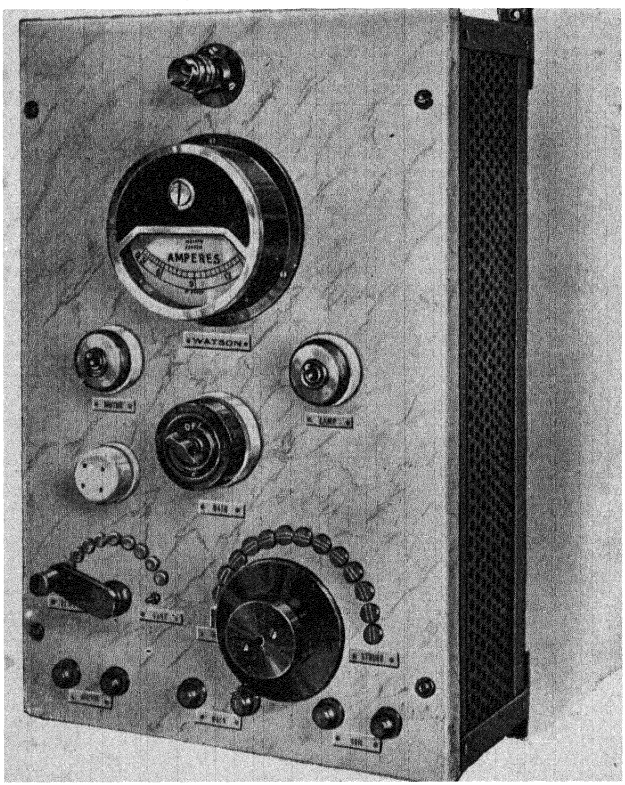


FIG. 4. Complete switchboard for coil and interrupter.

coils are usually mounted on a slab of marble or in an iron frame and are very often placed behind the switchboard.

In Fig. 4 is seen a resistance in which there are a number of studs provided with contact handles

which can be slid on to any one of them. The more usual and more convenient arrangement is to have the resistance mounted on a frame working behind the complete switchboard as shown; above the regulating resistance there is the main switch, and on each side of this safety fuses are provided for the primary circuit, and at the

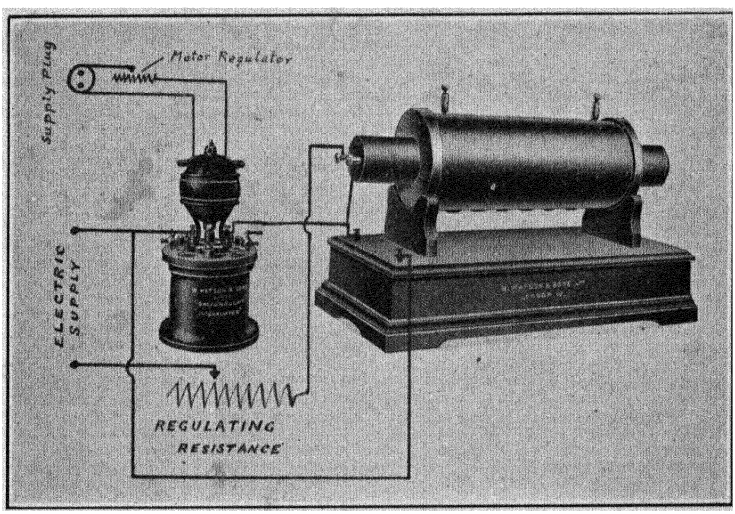


FIG. 5. Connections of coil primary with mains, interrupter, regulating resistances, and condenser.

top of the switchboard voltmeter and ammeter by which the amount of energy taken up by the primary can be seen at a glance. In the illustration the coil, milliammeter, and tube are shown mounted above, and the interrupter below.

An indispensable part of the induction coil when used with a mercury interrupter is the condenser. The interrupter itself serves to cause

the induced currents in the secondary winding; the primary current being alternately 'made' and 'broken,' the induction through the secondary coil changes, and an induced electro-motive force is produced in it, of opposite direction when the primary current is made to that when the primary is broken.

One of the functions of the condenser is to increase the length of the make, and to increase the abruptness of the break; it greatly reduces sparking at the interrupter when the current is broken, and thereby increases the rapidity with which the primary current stops. One effect of this is that the secondary voltage is greatly increased at the break, so that far more electro-motive force is produced at the breaks than at the makes, with the result that the secondary discharge is more or less uni-directional. The smaller currents discharging from the secondary are known as *inverse* currents, and although these have been greatly suppressed in the best make of induction coil, a certain amount of inverse current is invariably produced, and is eliminated by the use of valve tubes or rectifying appliances, which are discussed later.

The condenser is usually mounted in the base of the induction coil, and only rarely requires attention. It consists of two series of interleaved tin-foil sheets, each sheet separated from the adjacent ones by means of paraffin-waxed paper

(Fig. 7), the two ends being connected with the two terminals of the interrupter, *i.e.* shunted across it.

It occasionally happens that one of the insulating sheets will become pierced, when the spark of the coil will become watery, and greatly reduced in length. The condenser will then have to be repaired. When dealing with very powerful installations, a spare condenser will be found a useful accessory in case of need.

The hammer interrupter for alternately making and breaking the primary current is now obsolete, and is only occasionally used in the construction of portable coils. The mercury interrupter and the electrolytic are almost universally employed, and full descriptions of them will be found in makers' catalogues and X-ray treatises. A jet of mercury is made to rotate, and so thrown against a set of fixed contacts, each time the mercury strikes a contact current being enabled to pass across the interrupter circuit. In most cases a small motor, driven from a separate source (*i.e.* the mains, or from a secondary battery), is fixed above the interrupter, providing the power for driving the mercury by centrifugal force into the jet or jets. The Dreadnought interrupter of Messrs. Watson and Sons, Limited, is seen in Fig. 6; the driving motor is seen fitted above the top, and the motion imparted to *E* forces mercury through the jets *BB*; these jets strike the contacts

CC. To prevent sparking, gas is used to form a di-electric; gas from the mains or from an inflated rubber bag being forced through the interior before starting up, and a very small amount of gas being allowed to pass through during working, or for a few seconds between each exposure. Care must be taken that the gas has completely expelled

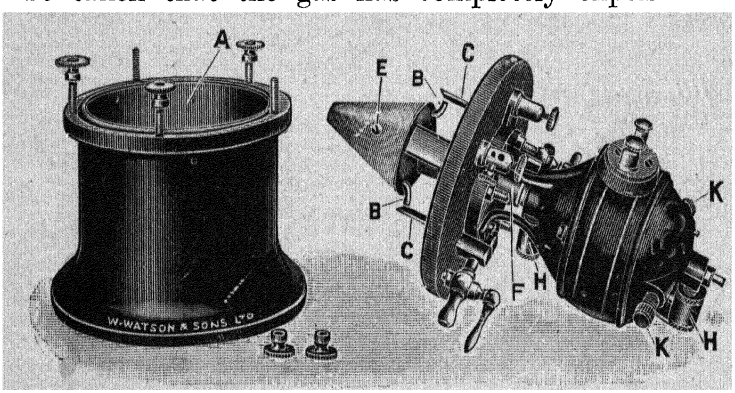


Fig. 6. Mercury interrupter, showing construction.

all air from the interrupter interior before it is started up.

A great deal depends on the efficient working of the interrupter, which should be frequently cleaned. It must be taken apart for this purpose, and the mercury carefully emptied out into a dish or beaker, and the scum removed by filtration. The mercury can be gently squeezed through a piece of clean washleather, or it may be cleaned by gently agitating it with a piece of crumpled-up moist filter paper, a dry filter paper being afterwards worked through it several times to take

up any moisture. The interior parts of the interrupter should be wiped with a piece of soft rag, and the contacts kept quite clean. The commutator of the driving motor will also require occasional cleaning.

In order to facilitate joining up, or tracing out a faulty connection. the wiring arrangement is shown in Fig. 5. One terminal of the electric supply leads direct to the regulator of the coil resistance, the other terminal of the *resistance* leading to one terminal of the primary. The other terminal of the electric supply is connected to (i) one terminal of the interrupter, *and* (ii) one terminal of the condenser, shown on the coil base.

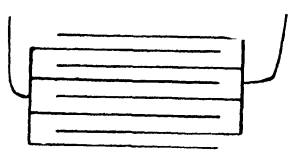


FIG. 7.

The second terminal of the interrupter is connected to (i) the second terminal of the primary, *and* (ii) the second terminal of the condenser. A separate plug would be used for connecting up the motor, as shown; one wire leading direct to the motor, the other leading to it *through* the small regulating resistance by which its speed, and hence the number of interruptions per seconds, is controlled.

The electrolytic interrupter, originally devised by Wehnelt, is of far simpler construction, and can be used with continuous current of 65 volts

upwards. It interrupts the current with extreme rapidity, and allows a large quantity of energy to pass, and is therefore suitable for work where very rapid exposures are to be given. The simplest

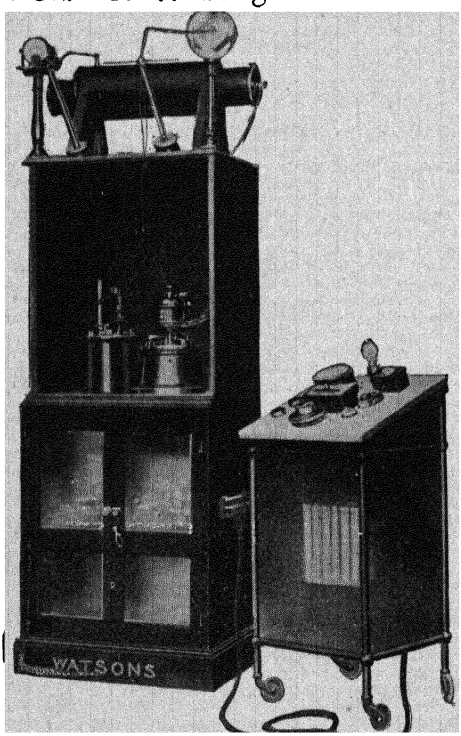


FIG. 8. Complete X-ray installation by Watson, showing interrupter and rotary rectifier beneath.

form is seen diagrammatically in Fig. 9. *L* represents a large lead electrode, *P* a platinum point projecting from a porcelain tube of conical shape, both immersed in sulphuric acid of specific gravity 1·2; this may be made by mixing one ounce of concentrated acid with 5 ounces of water. Some-

times as many as six platinum electrodes are used, more usually three.

When current passes through the solution, the platinum electrode (positive) becomes heated and small bubbles of gas are produced owing to electrolysis of the water, and these interrupt the current. A spark then takes place at the anode, explodes the gases, and the platinum again comes into contact with the acid ; these interruptions take place very rapidly, 1000 to 2000 per second being produced with only one anode. Considerable noise is caused by these interrupters when working and a sound proof box is often supplied to enclose them.

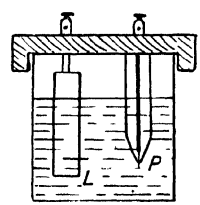


FIG. 9.

The X-ray tube is described in the next chapter, but a few remarks may be made here about tube stands, etc. In practically all methods of estimating the exposure a milliammeter is employed, and the tube should be connected with the coil via a milliammeter, and with one or more rectifying valve tubes in circuit to suppress inverse current.

The best type of milliampèremeter has a zero point in the centre of the scale on the dial, and reads in either direction, *i.e.* to right or left ; this saves having to connect the + terminal to a special terminal of the meter. A useful instrument for general work should read up to 15 or 30 milliampères, and most instruments are provided

with a shunt coil which makes the reading represent ten times the current; thus with the milled head

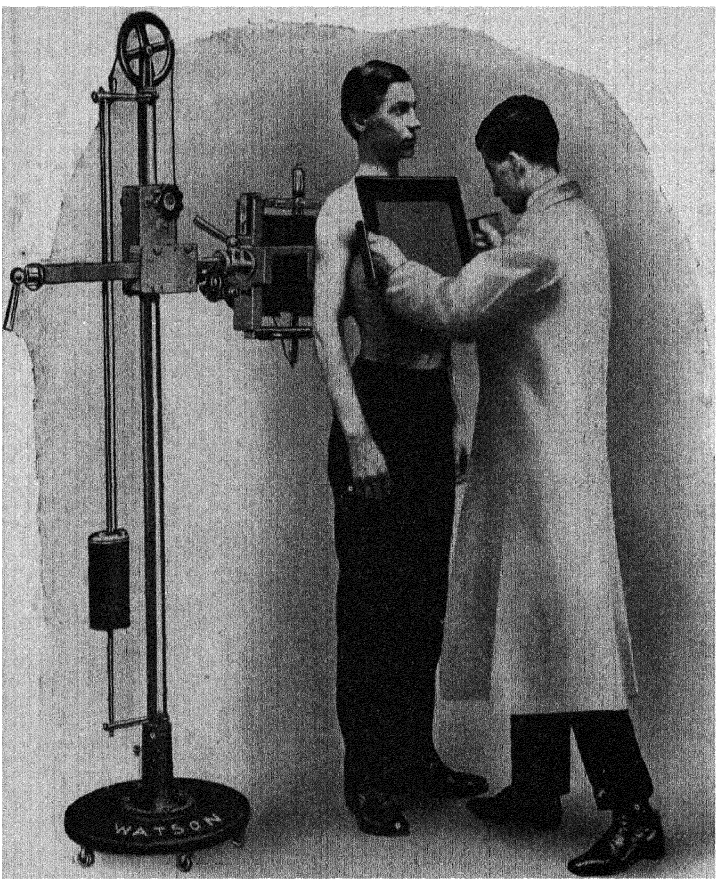


FIG. 10. Adjustable tube-stand, by Watson.

provided in the first position, the reading will be direct in milliampères; if the milled head be turned into the '10' notch, a reading of 3 milli-

ampères will represent 30, and so on. This device of course makes the range much greater, while giving greater accuracy on the lower readings.

The milliammeter, as well as the valve tube or tubes, must be supported on suitable stands and carefully insulated. It must be borne in mind that very high voltage currents such as are used to excite the X-ray tube will readily 'creep' across damp or dust, and apart from the danger of making apparatus 'alive' so that minor shocks may be felt on touching it, a great deal of the secondary energy may be needlessly dissipated and the output of X-rays suffer correspondingly.

The tube stand usually provides vertical and horizontal motion to the tube box or holder, and these movements should be very easy, despite the somewhat heavy nature of a tube stand, necessary to secure rigidity. The tube holder may be made of wood, lined with lead rubber, or a lead glass tube shield may be employed. In either case, the arrangement should be such that the beam of rays from the anticathode alone emerges from the tube holder, and a fluorescent screen held at the sides or back of it should show little or no signs of fluorescence. A universal ball and socket joint is often provided to enable the tube to be placed at any angle, and diaphragms for screening the rays or limiting their field should be provided with the tube box.

Where an X-ray couch is provided, the tube box is usually placed beneath, and the more

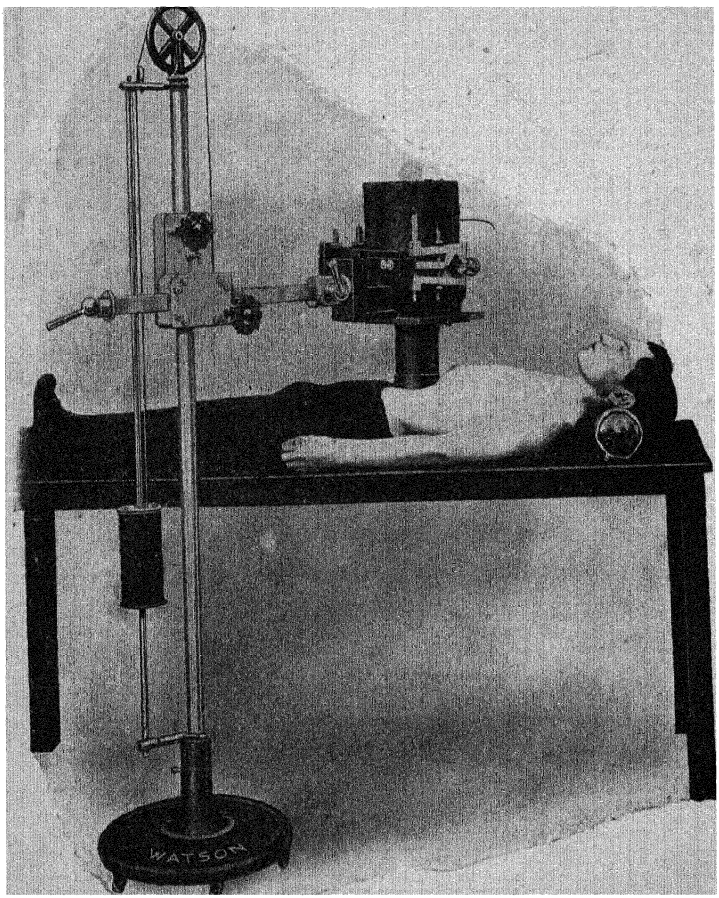


FIG. 11. The same stand, with compressor, in position for radiography.

recent couches are fitted in addition with the necessary movements and measurement devices

for localisation. The two illustrations, Figs. 10 and 11, show a stand [1] with which the tube can very readily be adapted for use for screen examination or for photographic work above or below the couch.

The secondary circuit connections are seen in Fig. 12, where M is the milliammeter, V_1 and V_2 the two valve tubes (one valve only need be

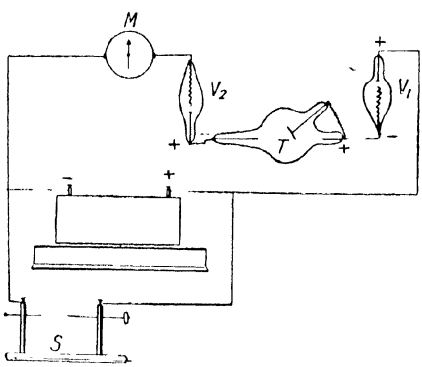


FIG. 12. Diagram showing connections of coil, alternative spark-gap, valve tubes, milliammeter and X-ray tube.

employed in very small installations, and it can then even be dispensed with if desired, though this is never recommended), T is the tube, and S the spintermeter showing the alternative spark-gap.

When a coil is switched on, it occasionally happens that through some faulty connection the apparatus does not function, and a lack of knowledge of the general connections and construction of the apparatus frequently leads to an expert

[1] Watson and Sons, Ltd.

being called in; this should only be necessary in the case of actual breakdown, which fortunately is very rare.

Accumulators are a constant source of trouble, as they are frequently run down when wanted, and if used in this condition, the coil will keep stopping, and the intensity of the rays be very low. It is fatal to an accumulator to attempt to use it in this condition, and it should never be allowed to run down too low. A small voltmeter should be connected with the terminals *before* the accumulator is used; when fully charged it may show up to 2·1 volts per cell, when nearing discharge the voltage will drop considerably, and 1·8 volts per cell should be regarded as the lowest admissible before recharging. In a battery of twelve cells the voltage thus drops from 25·2 to 21·6, and it must be remembered that this drop of over $3\frac{1}{2}$ volts, or nearly 14 per cent., will materially affect the penetration and exposure in a small installation.

Failure to start up, where the coil is working off the mains, or from a small generator, can only be due to a wrong connection, an imperfect or loose contact, or to the interrupter. Terminals, screws, and the nuts clamping the wires in a resistance, as well as those on the switchboard, have a habit of working loose at times, and by going over every connection in the circuit a fault can usually be detected in a few minutes. Spring arms pressing against contact pins are sometimes used by

manufacturers, as in the moto-magnetic interrupter of Watsons, etc., and these occasionally get corroded, and require scratching or rubbing with emery or with a smooth file.

A small, cheap galvanometer will often be found useful, which can be connected in series with a dry cell or two, and any circuit tested for continuity, or any part of the circuit. In this way a faulty or loose connection can quickly be traced, and it is a much more satisfactory way than using the main current.

The methods of varying the secondary current in either coil or transformer, and the control of the Coolidge tube, etc., are omitted here, as the majority of text-books on radiology deal with them.

The reader is referred to section F of the appendix, where the subject of the protection of the operator and patient is dealt with. This matter is one which demands the most careful study of all engaged in radiology.

CHAPTER II

The photographic plate: its characteristic properties—Special features of X-ray plates: speed: estimating exposure—Radiometers.

THE photographic technique of X-ray work differs considerably from that of ordinary photography, and requires careful study even by those who may be skilled photographers in the ordinary sense.

It is somewhat unfortunate that the photographic side of the work is so frequently neglected; expensive and elaborate apparatus is often used in order that short exposures may be given; great efforts are made on the part of the manufacturers to provide high penetration and power, and unless the capacity of the output and skill of the operator is followed by sound photographic practice the net result may be greatly vitiated.

X-ray plates differ considerably from the plates used in ordinary photography. Usually, but not necessarily, they are far less sensitive to ordinary light than so-called extra rapid plates, but they are very much faster when compared under the influence of the X-rays. The plate is prepared by spreading evenly over a sheet of carefully cleaned glass an emulsion containing silver bromide

with a small percentage of silver iodide. The emulsion is prepared by adding a solution of silver nitrate to a solution of ammonium bromide (and potassium iodide) containing gelatine, when silver bromide is formed according to the chemical equation :—

$AgNO_3$	+	NH_4Br	=	$AgBr$	+	NH_4NO_3
Silver nitrate	plus	ammonium bromide	yields	silver bromide	plus	ammonium nitrate.

The silver bromide is a creamy white salt, insoluble in water, and becomes emulsified with the gelatine and thereby held in suspension. Ammonium nitrate, the by-product, is an extremely soluble salt, and is removed by allowing the emulsion to cool, squeezing the jelly through a silver gauze, and washing the shreds into which it is thus broken up in several changes of water. The jelly is then melted up again and distributed by a coating machine over the glasses, which run under the coater on an endless band over which cold water is flowing in order to ensure rapid setting of the emulsion.

Despite the apparent simplicity of making a plate emulsion, the refined methods by which rapidity is obtained have been the outcome of many years of elaborate and very costly research. By varying the viscosity of the solutions, the temperature at which they are mixed, the rate of mixing, the amount of ammonia present and the

form in which it is employed, and the subsequent digestion, or cooking, of the emulsion to 'ripen' it, plates with great variation in their qualities can be produced.

The X-ray plate must be coated with an emulsion in which the silver bromide is in an excessively fine state of division, when it is most opaque to the rays; it must be very richly coated, in order to absorb as large a percentage of the rays as possible, and so on. It has become, by constant improvement, markedly superior to any ordinary plate for radiography, and no operator would now use an ordinary plate where an X-ray plate is procurable, except for such simple subjects as the hand or wrist.

There are several makes of plate—the Imperial, Ilford, Wellington, Sunic, Wratten and so on—each one possessing some individual characteristics; the general run of X-ray plates has to-day reached a high state of perfection, but there are nevertheless both chemical and physical features which require study and consideration, in order to obtain the best results. These will be fully dealt with in due course.

It may be of interest at this stage to give a brief idea of the method in use for comparing one plate with another. Probably two makes of plate, which when exposed equally under an ankle and developed together appear to be of the same rapidity, may have a different relative speed if

the comparative exposure be made through the chest or hip. There would appear to be some substantial difference between the chemical action of the soft and the very penetrating rays. The broad function of the rays is, however, to act on the silver bromide in the plate and produce in it a chemico-physical change of such nature that when the plate is developed, the exposed parts are reducible by a developer. The black image consists of metallic silver—black by nature of its chemical reduction—and the image before development is spoken of as the *latent image*. The *unexposed* portions of the plate will sometimes darken on development; this is known as *fog*. Fog may be produced by keeping plates too long before use, or storing them in too warm or damp a place, or by not exercising care to keep them away from any source of X-rays.

When comparing one plate with another, we have to examine the following properties:

(1) Speed.
(2) Density giving power.
(3) Gradation, *i.e.*, the degree of contrast between portions of the film differently exposed.
(4) Freedom from fog (or tendency thereto).
(5) Mechanical defects, such as tendency to frill at the edges, or to blister, in hot weather.

In a monograph on the Hurter and Driffield system of plate measurement, Mr. Vero C. Driffield says 'we define a technically perfect negative as one in which the opacities of its gradations are proportional to the light reflected by those parts of the original object which they represent.' A radiographic negative is one in which the opacities are more or less proportional to the X-rays reaching the plate through the different parts of the body which they represent. The opacity—the inverse of transparency—means the fraction of the incident light transmitted by any given part of the negative; in photographic work we usually employ the term 'density,' which is merely the logarithm of the opacity; the quantity of silver reduced in any part of the negative is proportional to the density. Hurter and Driffield employ a factor which converts the density into the weight of the silver per unit area, and by making careful investigation of the relations between density, gradation, and exposure they discovered the law which expresses the action of light upon the plate. We have in this book to deal with the effects of the X-ray upon the plate, which are more complicated on account of the very varying character of the X-ray beam. But we shall endeavour to show, by means of measurements of the densities of parts of negatives exposed under different thicknesses of aluminium, etc., how the relationship between the densities and intensity of the rays

is, as in the case of light, determined by the exposure.

The value of giving a little practical thought to this matter will be found in the fact that, once the exposure is made, little can be done to modify the result afterwards; that correct exposure is essential for the production of good negatives; and that the character of a plate can be readily

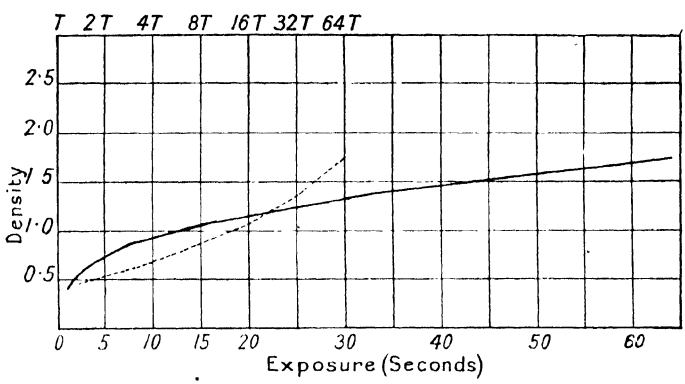


FIG. 13. Curves showing relationship between exposure and density in the negative.

ascertained by simple tests of the relation between exposure and density.

We can gather a good deal as to the general character of the X-ray negative and its recording powers from the curves shown. In Fig. 13 is shown the relation of the densities in successive portions of an X-ray plate exposed for 1, 2, 4, 8, 16, 32 and 64 seconds—the exposure being doubled in each case. The rise in density is considerable,

for exposures up to 8 seconds (1 milliampère through the tube, $4\frac{1}{2}$ inches equivalent spark-gap); it then rises less gradually as the time of exposure increases.

If we take as abscissæ each division of exposure representing a doubling of the exposure, we get the dotted curve, showing a fairly uniform gain in density for exposure increase.

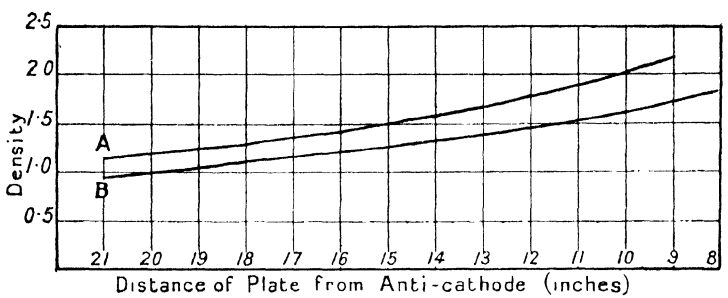


FIG. 14.

Turning to Fig. 14, we see two curves *A* and *B*, obtained by plotting against exposure the densities obtained on small strips cut from the same plate, exposed at 6, 7, 8, etc. to 19 inches from the anti-cathode; *B* was exposed to the tube when screened by 1 millimeter of aluminium. Here again we see a gradual fall in density as the plate is exposed further from the tube, the effect of the aluminium being not to alter the character of the curve, but merely to decrease density slightly.

An important point has cropped up during the measurement of some hundreds of X-ray plates

which deserves serious consideration, and is indicated in Fig. 15. The author's radiometer (*vide* p. 34) was used in the tests, and the curve shows the densities obtained in the negative when exposed through 1 to 12 thicknesses of $\frac{1}{16}$th inch aluminium. It will be seen that as thickness of aluminium is increased, *i.e.* as harder and harder rays cause the photographic effect, there is a distinct fall in density to a certain point—the $\frac{5}{16}$ths inch of aluminium; for the next five extra

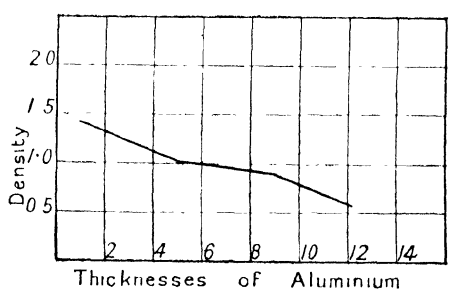


FIG. 15.

thicknesses we get very little decrease in density; then, after $\frac{9}{16}$ths inch of aluminium, the density again falls considerably for further extra thicknesses. These results indicate that there is a certain hardness of X-ray which gives very little contrast in the negative, and that exposures made with rays of such hardness cannot be expected to give negatives with good differentiation. The matter is one which deserves attention, and the author hopes shortly to publish some further details on the matter.

In practice we may take it that the photographic plate gives us a regular *scale of gradation* corresponding to the different opacities of the various parts of the body, until a point is reached where the rays cannot penetrate greatly any further, either by reason of too weak an installation or too short an exposure. It is impossible to get the same degree of contrast, in one plate, between the very opaque parts of the body and the less opaque parts; in the thicker parts of the body, unless the installation be sufficiently powerful, we are not likely to get strong contrasts as we can do readily when dealing with the hand, ankle and so on. Moreover, the more penetrating rays do not appear to produce the same degree of contrast as soft rays.

The three diagrams shown in Fig. 16 may make the question of gradation clearer. Here are seen three 'curves' *a*, *b*, and *c* representing three types of negative; *b* represents a normal negative, and *c* represents a negative in which the contrasts are too strong or severe—the black parts are too black, the grey parts too weak; *a* represents the reverse case—a 'soft' or 'weak' negative, such as is obtained by over-exposure and short development or radiographing the chest, for example, with a tube not giving sufficient penetration. *B* represents the various degrees of density in parts of a negative exposed under opaque bodies of equal differences of thickness,

showing roughly that we get equal increases in density for equal diminutions in opacity, over a certain range covering most of the cases met with in general practice.

If the character of the negative looked at from this standpoint be understood, it will be more easy to judge what is wrong with a faulty negative.

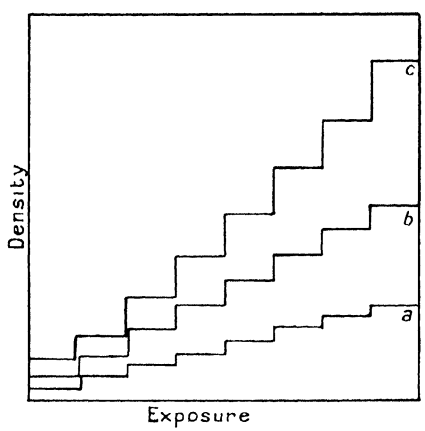


FIG. 16.

As will be seen in the chapter dealing with development, it is possible to counteract excessive contrast or density, or on the other hand any tendency of the negatives to be too flat or weak.

A method of estimating the relative sensitiveness of different plates was communicated in August 1918 to the Royal Society of Victoria by Miss N. C. B. Allen and Professor T. H. Laby. The plates to be tested were exposed in strips, developed at a standard temperature (20° C.)

for a constant period, and the densities of the various sections determined by a polarisation photometer. The natural fog of the plate was deducted from the density readings.

The exposure E was defined by

$$E = V^2 it/d^2,$$

where V represents the voltage applied to a Coolidge tube, i the quantity of electricity passing through the tube, measured in coulombs,[1] and t the duration of exposure ; d represents the distance of the focal spot from the plate. Three values were used for V, viz., 31,500, 73,000 and 83,000. The current varied between 0·03 and 0·06 milliampère.

The speed of the plate was defined as the reciprocal of the exposure required to produce a density in the negative of 5, as measured on the lines of Hurter and Driffield.

The density produced was found to be constant in the same plate for a constant value of the exposure over the range $V=31,500$ to $V=83,000$, and for a moderate variation of i and t, showing that within limits the density depends on the energy of the X-rays rather than their wavelength. We have found this not to be the case when the voltage rises very much, and the authors point out that their own experiences are the same where i or t vary greatly.

[1] A coulomb represents the passage of a current of one ampère for one second.

The 'speed numbers' obtained show certain X-ray plates to have a speed of ·00015, for example, as against ·000028 of a make of ordinary photographic plate, showing a great advantage in speed of plates specially prepared for use with the X-rays.

As a radiometer for obtaining the data previously discussed as to the density of a negative for varying amounts of exposure, we have constructed the apparatus shown in Fig. 17, where each successive step consists of one extra millimetre thickness of aluminium. Sixteen such steps are provided, 1 to 8 in one radiometer, and 9 to 16 in another. The size has been made so that the two radiometers can be laid side by side upon a half-plate. The densities obtained are then determined by means of a photometer giving readings in direct logarithms of the opacity.

The other method, used in preparing the curve shown in Fig. 13, depends on exposing successive strips of a plate to the X-ray beam for varying times. This method has been used by L. P. Larkin,[1] as a means of dosage measurement, using photographic paper exposed for varying times, such as 120 seconds, 108 seconds (a tenth less), 96 seconds, etc., and developing so as to get a graduated scale of tints. An interesting test was made with five such paper strips exposed to a tube run from a high tension transformer giving

[1] *American Journal of Röntgenology*, Sept. 1919.

45, 50, 55, 60 and 65,000 volts respectively. The results showed approximately that for each increase of 5 K.V. a tenth less exposure was required to produce the same depth of image.

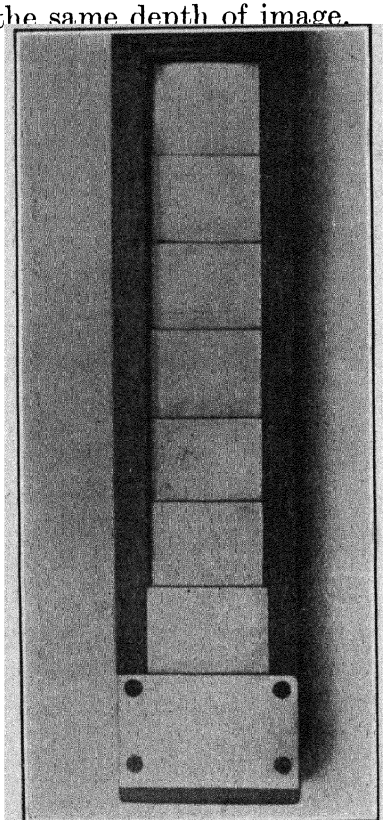


Fig. 17. Thorne-Baker Radiometer. Two of these are used side by side, one giving 1 to 8 variations in thickness of the aluminium, the other 9 to 16 thicknesses.

The chief factor in turning out successful radiographs is to give correct exposure with rays of the right penetrating power, and this can only be done, with the varying character of the subjects

photographed, as a result of long and constant practice. The penetrating power of the rays depends primarily upon the voltage applied to the tube terminals. The voltage of the secondary current in any given coil depends on the voltage of the primary current, and this can be regulated within the limits of the coil by varying a resistance shunted on the primary circuit. With a given voltage, we can only increase the penetration by the use of a larger coil; hence induction coils capable of giving a 15 or 20-inch spark will enable work to be done that would be impossible with a 10 or 12-inch coil. The alternative is, of course, to give longer exposures; but, as has been very clearly shown in the recent work done on radio-metallography (discussed later), there are limits to the penetrating power of any coil, and thus it would be waste of time for those possessing a small 6-inch spark coil to attempt work with no matter what exposure, that really requires a 12-inch spark or more.

Most hospitals are necessarily equipped with apparatus of sufficient power for all ordinary routine work; the advantage of unusually powerful apparatus lies in the ability it affords one to give very rapid exposures. This diminishes the chance of diffusion of the image owing to movement on the part of the patient, as well as of secondary radiation, and in some cases lessens the discomfort of the patient during the exposure.

The penetration of the tube may be judged by means of various apparatus, perhaps the most commonly employed being the Benoist radiometer, which consists of twelve sectors of aluminium of different thicknesses, from 1 to 12 millimetres, with a central disc of silver foil 0·11 millimetres thick; the radiometer is examined with a

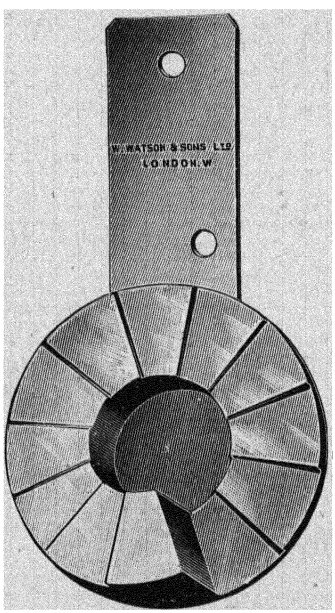


FIG. 18. Benoist aluminium radiometer.

fluorescent screen; one of the aluminium sectors will appear of the same density as the central silver disc; the number of this sector gives the 'hardness' of the tube in Benoist units. According to Kaye, 'a notion of the discharge potential across a tube may be got from the very rough

relation that the voltage is from 6000 to 10,000 times the Benoist reading of the X-rays.'

The Wehnelt radiometer consists of a wedge-shaped aluminium strip, with a flat silver strip mounted on one side, and a copper strip on the

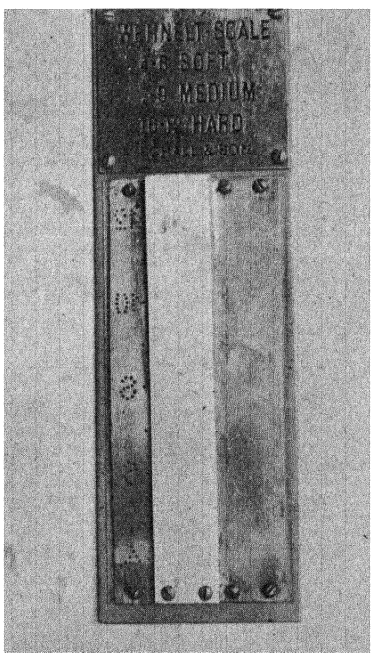


FIG. 19. Wehnelt penetrometer.

other containing perforated numbers; examination with the screen will show what part of the wedge appears of the same opacity to the rays as the silver strip, and the number on the copper strip gives the degree of hardness: 4 to 6 represents a soft tube, 7 to 9 a medium, and 10 to 12 a hard tube.

Platinum foil of varying thicknesses is used in the Walter radiometer, the thickest foil visible on examination with a fluorescent screen giving the hardness.

In the estimation of exposure, however, not only is the hardness of the tube required, but the milliampères passing through it. The hardness represents the penetration, the milliampère seconds the quantity of current. Most exposure tables are given in milliampère seconds, but the alternative spark-gap may be used as an indication of hardness.

As a rough indication of exposure, we may take the following cases, the distance between the anticathode and the plate being 18 inches, and the Benoist hardness 6:

Shoulder . . .	75	milliampère-seconds
Skull, taken transversely . . .	140	,,
Thorax . . .	75	,,
Femur . . .	90	,,
Knee-joint . .	60	,,
Kidney . . .	180	,,
Wrist . . .	12	,,

(In the two latter cases the hardness should be 4 to 5 only.)

The term 'milliampère-seconds' implies the number of milliampères passing through the tube multiplied by the number of seconds exposure. Thus with 3 milliampères, in the radiography of

a knee-joint the exposure would be 20 seconds, with one milliampère an exposure of 12 seconds would be given for a hand, and so on.

Much depends on the patient, needless to say; thus the slight hand of a woman would require less exposure than the heavy hand of a mechanic; in some American technique, for kidney work, and thick parts of the body, the patient is weighed, and a 'weight factor' introduced in calculating the exposure. But as already stated, experience alone will enable one to deal with successive cases with certainty. There is some diversity of opinion, too, as to whether the distance between the anticathode and the plate should be varied, and whether the amount of current put through the tube should be varied; in the standard outfit made by the General Electric Company for use in the United States Army these two factors are recommended to be kept constant, and Dr. Coolidge gives a table of exposures, the tube being run with a fixed amount of current, and the distance between anticathode and plate being always 18 inches. This method of procedure is not generally looked upon with favour in this country.

The condition of the tube, the equivalent spark-gap (p. 19), and the nature of the plate, with an installation of any given size, therefore govern the exposure, so far as a body of a given opacity is concerned. The operator is not faced

with so many difficulties to-day as he was a few years ago as regards the tube. Tubes have been brought to a high state of perfection, comparatively speaking; they nevertheless require constant care, attention, and observation.

As a preliminary it may be remarked that far too little care is taken usually to keep the tubes clean on the surface. External dust and damp are reponsible for many of the troubles one

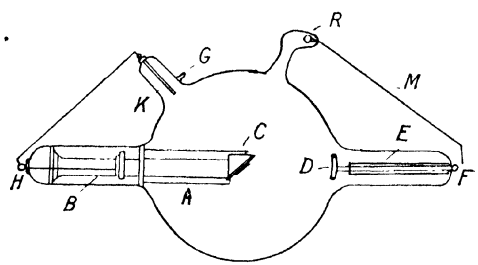


FIG. 20.

meets with; damp or dust will allow current to stray across the tube instead of passing through it; and dust is frequently the cause of the tube puncturing, *i.e.*, becoming perforated with a minute hole so that there is no longer a vacuum; in these cases the tube is generally ruined. Any tube that is in use should be kept scrupulously clean; it should be carefully wiped over with a piece of dry linen every day, the metal parts cleaned and all damp or dust assiduously removed. The life of a tube can in this way be considerably lengthened, apart from the more regular working

that results, and the greater ease of estimating exposure.

The diagram in Fig. 20 shows the various parts of an ordinary X-ray tube.

The following are the principal parts :

A Anticathode stem.
B Supporting tube for anticathode.
C Anticathode.
D Cathode (negative electrode).
E Cathode stem.
F Cathode terminal.
G Point at which the tube was exhausted.
H Anode terminal.
K Anode (positive electrode).
M Regulating wire arm.
R Regulator tube.

The cathode is slightly concave, in order to provide a means of focussing the stream of cathode rays upon the anticathode ; the latter is inclined at an angle of 45 degrees, so that the X-rays travel along a path perpendicular to *BC*, to the fluorescent screen or photographic plate. The anticathode is usually made of platinum or tungsten ; it must essentially be of a heavy metal, in order to generate the maximum of X-rays, and must have a very high melting-point to withstand the intense heat generated by the cathode stream focussed upon it. Kaye found that the intensity of the harder rays is roughly proportional

to the atomic weight of the anticathode. Comparing the intensity of the rays with various metals, when working with a tube at about 25,000 volts, he found that with aluminium (atomic weight 27) the intensity was about 10, as against 55 with silver (atomic weight 108) about 90 with tungsten (atomic weight 184) and 100 with platinum (atomic weight 195). While when the potential on the tube was increased the heavy anticathode became slightly more efficient, the reverse appeared to be the case when the anticathode was made of the lighter elements. Tungsten is the metal chiefly used at the present time for the anticathode 'target.' Various devices are employed for the cooling of the anticathode. A copper sleeve welded to the anticathode target supported by a glass sleeve is frequently used, and in some tubes the metal sleeve is carried beyond the tube itself and terminates in some form of radiator to dissipate the heat. Water cooling devices are also in use; tests have been made recently with a Coolidge tube in which water circulated from the radiator of a Ford car enabled the tube to be run for twenty-four hours continuously.

The tube must be in proper working condition to give the best results, and inverse current, *i.e.* current which tends to pass in the wrong direction through the tube, must be, as far as possible, suppressed. The interrupter of the coil makes

and breaks the current in the primary circuit; at each make and break a high voltage current is set up by *induction* in the secondary, and that induced in the make is opposite in direction to that induced at the break; as explained in Chapter I. it is the function of the condenser to take up the current produced at the first instant of the make, so that it grows in intensity more gradually in order completely to magnetise the iron core: at the break, when the current is interrupted, the condenser discharges its current into the primary and makes the demagnetisation of the core much more rapid, resulting in a *high* induced current at break, while at make the induced current is relatively small; the feeble inverse currents produced, however, naturally pass through the tube.

If we fix a flat metal disc to one secondary terminal of the coil, and a piece of wire or pointed electrode to the other, and if the disc terminal be the negative (−) and the other the positive (+), sparks will travel from the point to the *centre* of the disc; if the disc be at the positive terminal and the wire at the negative, the sparks will travel to the *outer edge* of the disc. In this way the polarity of the coil can be ascertained. The anode of the tube must be attached to the positive terminal of the secondary, the cathode to the negative terminal. But as explained above, inverse currents will also pass

at every make of the primary circuit in the opposite direction. These may be avoided, or suppressed, by means of one or more valve tubes, according to the output of the coil which only admit of current passing through them in one direction, or by means of some form of spark-gap which only allows current to pass readily in one direction.

Valve tubes are frequently fitted with regenerators like X-ray tubes, and consist generally of a curved disc anode and aluminium or metal spiral cathode.

A tube connected to the coil, and alternative spark-gap, with a valve tube one either side of the tube, is shown in Fig. 12. If two tubes be used in this way, the vacuum of each should be so regulated as to be similar, and careful regulation will be constantly required if the tube itself is to run sweetly.

An alternative to the use of rectifying valve tubes can be found in a mechanical collecting device such as the Sunic rectifier; a revolving shaft fitted with two or four metallic points turns between fixed electrodes, which just graze the metal points and deliver the secondary current to them; by the time the inverse current tends to pass, the collectors have rotated to a point halfway between the fixed electrodes, and it is thus prevented from being fed to the tube.

Rectification is of course a simple problem in

a high tension transformer apparatus, and has been solved in a highly successful way.

The appearance of an X-ray tube working normally should be carefully studied ; if too hard there is an absence near the anode of gas of bluish appearance ; this blue appearance is accentuated when the tube is too soft, and a bluish stream may be seen, of cathode rays, between the cathode and anticathode. Inverse current shows itself

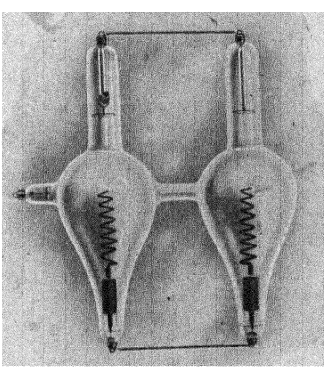


FIG. 21. Double rectifying valve tube.

as a bluish concentric band from the region of the cathode to the back of the anticathode support, while should the tube be wrongly connected with the coil, *i.e.* positive terminal to cathode and negative to anode, the soft green hemisphere opposite the anticathode will be absent, and instead there will be a bright yellow-green disc of light opposite, with the upper part of the tube blue and streakiness generally—the appearance is unmistakable.

Despite the high degree of exhaustion of the tube (the pressure is reduced to about one millionth of an atmosphere) the aluminium cathode and also the anticathode will contain a certain amount of gas, which is liberated when a new tube is first run; but gradually the tube will become harder, apparently because the gas left in it is gradually driven into the glass; lead glass shows this property less than soda glass. Along with the increased hardness comes a gradual blackening of the tube, due to the slow disintegration of the metal of which the anticathode target is made, and the finely divided particles of metal distributed on the glass also have an absorbent action on the gas in the tube and increase the rate of hardening.

A tube that has become too hard can be softened by running it for some time with a heavy current from a large coil. The regulating rod is, of course, designed to enable the tube to be softened. A small amount of current should be run through the tube at first, with the regulating rod an inch or so from the cathode terminal; the distance may be gradually diminished, the rod being frequently pushed back and the tube tested for hardness under normal running conditions. A new tube, carefully run for not too long periods, and not given too much current, usually attains a moderate state of hardness, in which it remains for a considerable time. The valve tube or tubes

similarly require occasional regulation by means of the regulating rod.

The two most important factors for obtaining sharp definition in radiographs are the sharpness and immobility of the focal spot of the tube. The focal spot can be photographed by means of what is practically a pin-hole camera ; a plate is exposed in a box covered with a sheet of lead perforated in the centre with a very small hole ; this hole, which acts as a lens, forming an image of the focal spot on the plate, is so placed as to be exactly opposite the centre of the anticathode, the target being at an angle of 45 degrees. The photographs shown in Fig. 22 were obtained by Monsieur H. Pilon, and show the focal spot with the tube worked at (1) 35,000, (2) 45,000, (3) 55,000, and (4) 65,000 volts, and, as will be seen, the dimensions of the spot are only slightly modified ; when, however, the ampèrage is varied, the size of the focal spots varies considerably, as seen in Fig. 23, where in *A* the milliampèrage was only a fraction of that used in taking *B*. The smaller the focal spot, the sharper the definition, and hence the value of the tungsten target so much used in modern tubes, the melting point of which is 3200 degrees C., so that the concentration of the energy upon a very small area does not cause melting of the target.

The result of investigations in the matter indicate that (i), it is an advantage to use tubes of

as high power as possible, so that the distance between the tube and the plate may be as great as possible, and (ii), to give as short exposures as possible in order to minimise relative displacements of the focal spot. Increasing the distance of the focal spot from the plate increases the

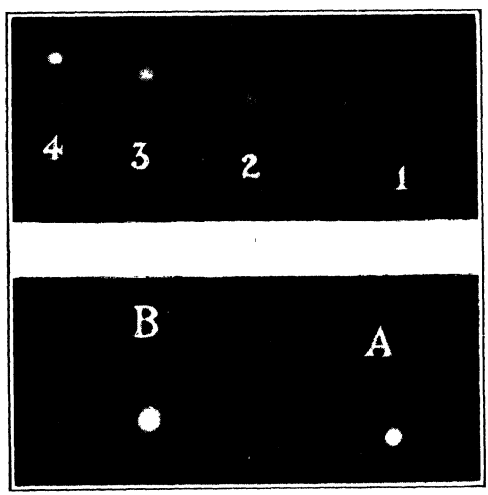


FIG. 22. Focal spot photographs, taken with pin-hole 'camera.'

relative difference between the distance of the focus from the object to be radiographed and the distance of the object from the plate, and thus leads to better definition in the negative.

The sharpness of the radiographic image is much affected by the distance of the tube from the plate; the beam has the shape of a conical pencil with its apex the focal spot of the anti-

cathode, or more probably a number of such pencils emanating from different points, and hence as the rays strike each edge of the object obliquely, the photographic image is enlarged, or spread. This spreading decreases in extent if the anticathode be further away, since the distance of the object from the plate remains the same.

A. Lumière [1] found that differences in the intensity of the current do not appear to have any appreciable influence on the sharpness of the image, and confirmed the recognised fact that the sharpness of definition increases with increasing distance between anticathode and plate, indicating that diffusion of image is due to the source of origin of the rays not being a point, but several points on the anticathode, caused by a shifting of the cathode stream.

Various methods of technique have been suggested for different subjects; Laquerrière and Pierquin [2] describe one for demonstrating the posterior aspect of the lower end of the humerus, etc.; Salmond [3] observes that to avoid gross distortion of the size of the heart and its great vessels, the distance of the anticathode and the plate should be at least 3 feet, and more if it can be conveniently arranged.

[1] *Journal de Radiologie et d'Electricité*, Dec. 1918.
[2] *Journal de Radiologie et d'Electrologie*, Mar. 1919.
[3] *Archives of Radiology and Electrotherapy*, Sept. 1919.

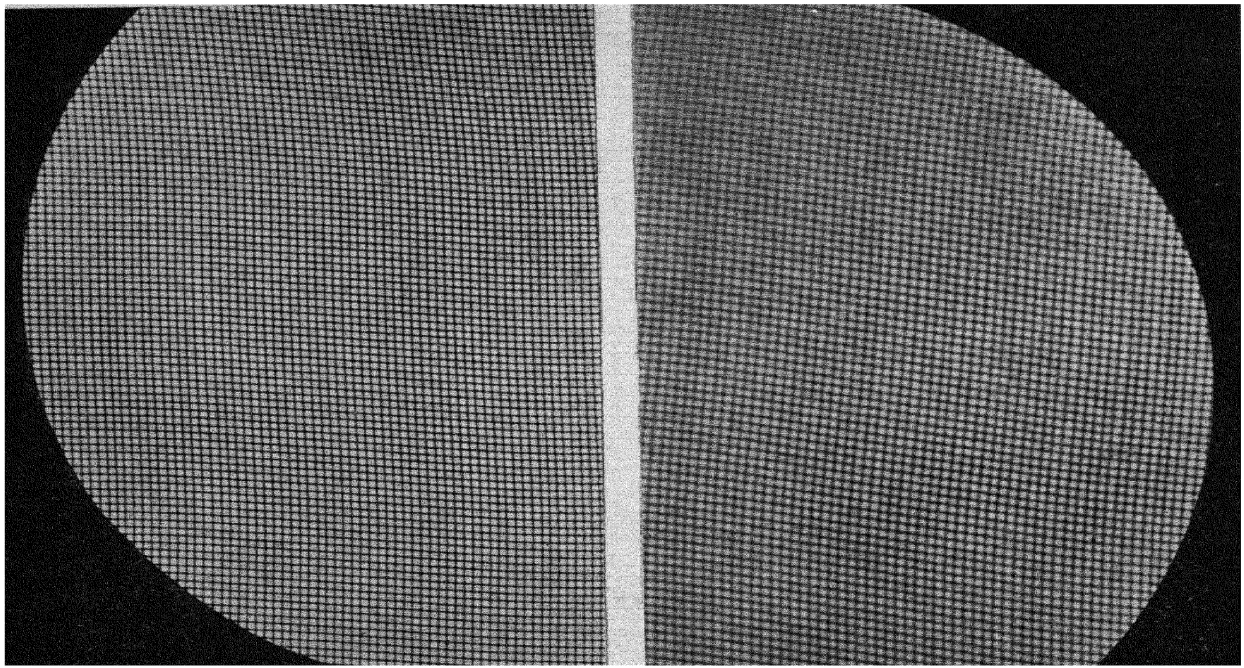


FIG. 23. Wire gauze radiographs, with the plate 12 inches from anticathode (right, *A*) and 24 inches (left, *B*).

In Fig. 23 are seen two radiographs of a fifty-per-inch mesh wire gauze, placed 2 inches from the plate; *A* is exposed 12 inches from the anti-cathode, *B* at 2 feet distance. A marked superiority in definition is seen in *B*.

When details of an exposure are given, it is often said that the tube was run 'at so many milliampères, backed up by a certain spark-gap.'

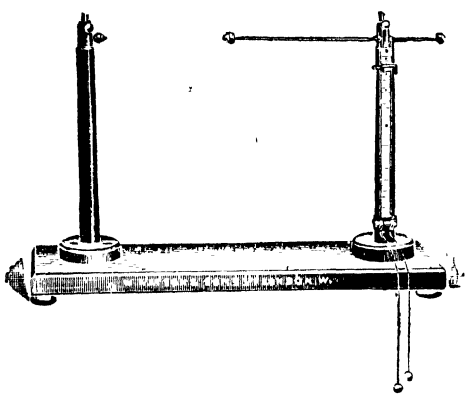


Fig. 24. Ordinary form of spintermeter, or alternative spark-gap.

This is a useful method of working, as it gives us some idea of the voltage passing through the tube, on which the penetrating power of the rays depends. A pair of sparking pillars, attached to the coil or placed on a base-board separately, are used, with two spark rods, one of which can be adjusted by means of a milled head. If the tube be of such hardness that a spark will occasionally just pass between the points of the rods

when they are 5 inches apart, the tube is said to be backed up by a 5-inch spark-gap, and so on.

The penetrating power of the rays is roughly proportional to the square root of the length of the gap; thus a tube backed up by an 8-inch spark-gap would require for a given subject only a fourth of the exposure required if backed up by a 4-inch gap. This only holds good for one particular tube, and can only be said to give a very rough idea of the length of exposure. One use of the alternative spark-gap is that it shows fairly readily when a tube begins to harden up; it can then be reduced in vacuum with the regulator and kept at a fairly uniform degree of penetration.

The effect of the plate speed upon the duration of exposure is one which requires comparative measurement. Most of the well-known brands of X-ray plate are extremely rapid, and approach within a little of each other as regards rapidity, though it is claimed for the Sunic plate that it is from one-third to half as fast again as any other brand.

A great reduction in the exposure can be obtained by the use of an intensifier screen, which is placed in contact with the plate during exposure. This cuts down the length of exposure to a tenth, or even a twentieth of that necessary with the plate unaided. These screens are there-

fore very extensively employed, and as they have been greatly improved during the last three years, and most of their original drawbacks overcome, they play an important part in the photographic technique.

the name of the patient and particulars of exposure, etc. may be written. The wrapped plates should never be brought into the operating-room until the coil and tube have been adjusted, and any fluoroscopic examination completed.

The repeated use of envelopes is rather dangerous; the paper gets worn, scratched, and some-

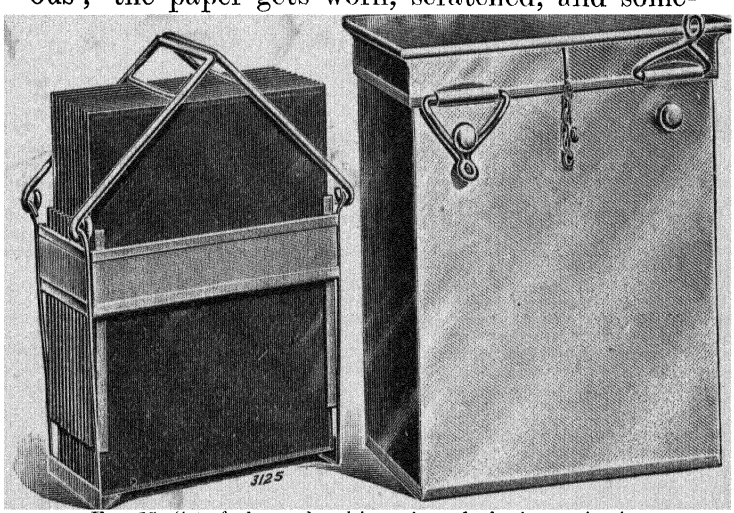


FIG. 25. Set of plates placed in rack ready for immersion in development tank.

times cut or punctured in use, and old envelopes are a frequent source of peculiar marks which appear on development and are usually ascribed to faults in the plates. Unexposed or exposed double-wrapped plates should not be left to stand about, even in the weak white light of the dark-room; they should be kept in a cardboard box, or better still, in the lead-lined storage box.

The previous chapter has been written with a

view to show the importance of giving a correct exposure in radiography. If this has been done, development can be carried out by routine methods which, if conducted on sound lines, will yield uniformly good results.

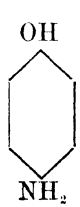
No matter what experience the radiographer may possess, there must come many occasions when the exposure given is not exactly what was wanted, and then a good result must if possible be obtained by manipulation in the development; failing this, some sort of 'after treatment' may be necessary, such as is described in the chapter dealing with intensification and reduction.

When a plate has been exposed to light, or to the X-rays, a change is effected in the silver bromide of the sensitive film, and an image, invisible to the eye, and termed the *latent image*, is produced. When the plate is developed, this image gradually becomes visible, the exposed parts of the film becoming black owing to the formation of pure silver, which in a form produced by chemical reduction (such as development gives) is black. When fixed, the negative consists of an image of pure silver in pure gelatine.

It is hardly within the scope of this book to discuss the nature of the latent image; it has led to a good deal of speculation, and may be due to some of the silver bromide being reduced by the action of the rays to silver sub-bromide, or due to a physico-chemical strain within the silver

bromide which so upsets equilibrium that a developer is able to bring about its reduction and so form the black silver deposit. When a plate is exposed to white light, the latent image would appear to be formed in the uppermost layers of the film, development proceeding downwards until the image goes right through the entire film. In the case of the X-rays, the film is exposed throughout its entire thickness, and development takes place throughout as soon as the developing liquid has permeated the film. X-ray plates, owing to the penetrating power of the rays, can be usefully coated much more richly with silver bromide than ordinary plates, thus imparting greater density to the image, or more 'speed' to the plate. A more vigorous developer is also employed.

There are a great many developing agents in use, and many more which could be used: eikonogen, hydroquinone, metol, pyrogallol, pyrocatechin, glycin, adurol, and so on. Most of the more recent developers are derived from phenol or cresol. Phenol (carbolic acid) has the chemical formula C_6H_5OH; amido-phenol $C_6H_5NH_2OH$; para-amidol phenol, represented by the graphic formula,



is the basis of many developers, whereas most of the metol substitutes are derived from cresol $C_6H_5CH_2OH$.

The function of the developer being to reduce the silver bromide AgBr to metallic silver, Ag, the bromine must clearly be set free ; this bromine either gives rise to hydrobromic acid HBr, which retards development, or must be reacted upon by an alkali and so absorbed to prevent retardation. Hence development with these organic developers requires the presence of an alkali, and caustic potash or soda or an alkaline carbonate is incorporated in the developing solution, greatly accelerating its action.

Developing agents being powerful reducers are themselves readily oxidised ; the oxidation products are usually deep brown or black, and this is the reason that old developers become brown, and simultaneously inactive. Some are much more readily decomposed than others, for example, metol and most metol substitutes.

A developer consists of three essential parts, the reducing agent itself, a preservative and an accelerator. Thus metol and hydroquinone—usually combined because the former gives good gradation, *i.e.*, an ample scale of detail of varying degrees of intensity, while hydroquinone gives great density and vigorous contrast—form together the reducer in the developer ; sodium sulphite, and frequently potassium metabisulphite,

acts as the preservative, and sodium or potassium carbonate as the accelerator. The sulphite is an unsaturated compound, and readily takes up any oxygen forming sulphate, thus:

$$Na_2SO_3 \text{ plus } O = Na_2SO_4.$$

By so doing it prevents the oxygen from attacking and discolouring the metol, etc. The accelerator does its work by neutralising the acid products of development as fast as they are formed, and the more of it there is present, the more rapidly will development take place, but at the expense of *density*.

The following formula, due to Dr. Martin Berry, is in use at many hospitals:

Water	20 oz.	or 560 cc.
Metol	20 grs.	or 1·3 gm.
Hydroquinone . . .	80 ,,	or 5·2 ,,
Sodium sulphite (crystals) .	2 oz.	or 56 ,,
Sodium carbonate ,, .	2 ,,	or 56 ,,
Potassium bromide (10% sol.)	80 mins.	or 5 cc.

We may take this as a typical example. First, freshly boiled or distilled water should always be used, as ordinary tap water contains a good deal of dissolved air, and therefore oxygen; boiling expels the air. Second, the solution should not be put into too large a bottle. If 80 oz. of developer is made up, and it is likely to last several days, it should be put up in four twenty-ounce bottles, as a half-empty bottle will obviously

contain half its volume of air, and this will eventually discolour the solution and partially exhaust its strength. These remarks apply especially to some of the earlier metol substitutes, but the latter have recently been greatly improved. The majority of organic developers were made, before the war, by the big German dye firms, who had devoted enormous energy and research to this branch of chemistry ; British manufacturers have done remarkably well to produce the developers they have done, and their products are now quite equal to the German ones. In the meantime, special attention should be paid to any such practical means of avoiding this oxidation trouble, as those above suggested.

In making up the above formula, the metol is first of all added to the water, and the bottle shaken until it has all dissolved ; the hydroquinone is next added and the bottle again shaken until this has dissolved ; next the preservative, sodium sulphite, is added, and this should be completely dissolved before the sodium carbonate is added ; this chemical, the accelerator, should be of the best quality, for the reasons stated later on. It will be seen that the carbonate is present in about ten times the quantity of the metol and hydroquinone ; the relation between reducing agent and accelerator varies with different developing agents, and its excess over the amount normally needed has a marked effect upon the

FIG. 26. Ulcer of body of stomach, and hour-glass contraction. Taken with a Snook machine, X-ray plate, and intensifying screen; ½ second exposure.

character of the image (*q.v.*). In the case of amidol no alkaline accelerator is used at all.

The potassium bromide or restrainer which is introduced to prevent fog, not only slows development somewhat, but undoubtedly destroys some of the very faint detail in the image, and it should therefore be used in as small a proportion as possible. Its effect appears to be to reconvert the latent image into silver bromide. It is very useful in cases of over-exposure, or when we wish to obtain increased contrast, but in either case it is really necessary to add it *before* development begins. Care must be taken to add only the exact weight of bromide given in the formula as it produces a marked effect.

The control of the character of the negative image which is possible by judicious development has been very little studied by radiographers. One reason for this is that in the routine work of a busy hospital, a large number of plates are dealt with every day, and there is little time to do anything but straightforward development, *i.e.* development for so many minutes in some standard solution. But it is not always possible to gauge exposure correctly, so that methods of dealing with both under- and over-exposed plates should be known ; besides this, different types of negative are frequently required—in some extra contrast is wanted to throw some part in relief, in others a soft negative full of fine detail is

needed, to show up delicate osseous structure, tubercular tissue, and so on.

A one-solution developer like that given above, while excellent for routine work in which the plates are, on the whole, correctly exposed within very fair limits, does not provide the means of control possible with a two- or three-solution developer. The following formula is one in which the reducer, accelerator, and restrainer are made up in separate solutions, the extra trouble of which will, on certain occasions, be amply repaid :

A.	Pyrogallol . . .	80 grs.	or	9·2 gm.
	Metol	70 ,,	or	8 ,,
	Potassium metabisulphite	180 ,,	or	20 ,,
	Water	20 oz.	or	1000 cc.
B.	Sodium carbonate .	3 ,,	or	150 gm.
	Water	20 ,,	or	1000 cc.
C.	Potassium bromide .	1 ,,	or	30 gm.
	Water	10 ,,	or	300 cc.

For normally exposed plates take equal parts of A and B, and add half a drachm of C to each four ounces of mixed developer (or 2 cc. to each 60 cc.). This will produce a vigorous negative, but the metol present in the solution will ensure ample detail and good gradation. Where over-exposure is feared, the amount of C may be doubled, or even trebled ; where under-exposure is suspected, three parts of B should be mixed with two parts of A, and half a drachm of C

added to each three ounces of mixed developer (or 2 cc. to each 90 or 100 cc.).

Any developer made up on these lines enables us

(1) to increase contrast by using more A, less B, and slightly increasing the proportion of C.
(2) to increase detail and soften contrast by using more B, less A.
(3) to counteract over-exposure by using more A, less B, and slightly more C.
(4) to counteract under-exposure by using less A, more B, and less C.

This means of control brings us to the question of gradation, already discussed on pp. 25 to 31. The illustrations on p. 31 will show in a graphic way the results of controlling development.

In the diagram, we have represented the densities in a negative by the steps shown, each corresponding to a given increase in exposure. The 'curve' *a* represents a flat negative, *i.e.* one in which the densities for the various increases in exposure are insufficient, the densest parts being too 'grey'; *b* represents a normally exposed and developed negative; and *c* a harsh negative with excessive contrast, the higher densities being too opaque.

Now if we take three similarly exposed plates we can produce an effect like *a* by using more B solution than A, or an effect like *c* by using

more A solution than B, or by adding bromide to the developer. It may be remarked that a warm developer will tend to increase contrast and produce a negative of the *c* type, while too cold a solution will tend to give one of the *a* type, especially where hydroquinone is used. Over-exposure and short development tends towards *a*, under-exposure and forced (prolonged) development to *c*, hence if a plate be obviously over-exposed we can control the gradation by adding more A solution with some bromide, bringing the result up to the *b* curve, and if the plate be clearly under-exposed we can bring its character down from the *c* to the *b* curve by adding some more B solution to the developer.

In developing X-ray plates it must be remembered that a good deal of the apparent density is lost in the fixing, and that owing to the large amount of sensitive salt in the film development takes longer than in the case of ordinary photography. The details must be watched, and one must aim at getting these sufficiently brought out that they are not lost in the fixing. Thus in a negative of a fractured wrist, for example, the fracture may be slight, and hardly visible unless the plate has been fully developed ; or it may be visible in the negative before fixing, and almost invisible *after* fixing.

There is a ratio between the time taken for the first appearance of the image and the time re-

quired for complete development, and development guided by this ratio is known as 'factorial.' The ratio, or factor, varies with the different reducing agents, though it does not vary greatly with different formulae in which the same reducer is used.

Working at about 65 degrees F. the following are the factors for the most frequently employed reducing agents:

Adurol	5
Eikonogen	9
Glycin	14
Hydroquinone	5
Metol	30
Metol-hydroquinone	14
Pyrogallol	5
Rodinal	30

The ratio can hardly be said to be the same in radiography as in ordinary photography, and the following experiments are suggested as a basis for guidance in obtaining uniform results. Make an exposure of a hand, or wrist, and another of some thick part of the body—known correct exposures—and develop each plate separately, carefully noting the number of seconds taken in each case for the image to appear, and the time taken for full development, the best possible results being obtained. Suppose the image of the wrist appears in 30 seconds, and development is complete in 4 minutes, the factor will be $\frac{4 \text{ minutes}}{30 \text{ seconds}}$, or 8. It

will then be fairly safe in all similar subjects to develop by factor, allowing eight times the time taken for the first appearance of the image. The factor found by experiment for the thicker parts of the body will probably be greater, and will be useful as a guide for similar subjects on the many occasions which occur when one is in doubt as to how far to carry development.

While strongly suggesting that a uniform temperature of 65 degrees F. be arrived at for development, it may be of interest to note that the time taken by a developer to give a definite degree of contrast varies with the temperature. The 'temperature coefficient' of a developer is the factor by which the time of development at a given temperature must be increased or decreased for every 18 degrees (F.) fall or rise in temperature. Thus Mees and Sheppard found the temperature coefficient of hydroquinone to be 2·8, metol 1·25, and rodinal 1·5. This may seriously affect stand development; thus suppose we are giving a plate 120 minutes' development with rodinal, the time taken for the first appearance of the image being 4 minutes (factor=30), development being at a temperature of 70 degrees F. On another occasion, with the developer much cooler, say at 52 degrees F., or 18 degrees lower, the time of development would be increased to 120 minutes×1·5, or 180 minutes. Big differences like this should never be met with in prac-

tice, but it is important to know that not only is the time of development considerably affected by temperature, but also the amount of contrast in the negative can be seriously reduced by using cold solutions.

A method of development much used in the United States consists in immersing the exposed plates for several hours in a very weak developer of between one-tenth and one-twentieth the normal strength. The advantage this method offers is that several troughs or tanks of plates can be dealt with at once, and that whereas in ordinary development the process must be watched throughout, in stand development an occasional examination of the plates every few minutes or so suffices.

Stand development has certain advantages where it is wanted to develop several plates at once, and it has come into considerable use during the last year or two. As a rule, it emphasises any tendency to stain—plates are sometimes met with which contract a slight yellow tinge on development, which affects the printing quality of the negative.

Grooved tanks can be obtained for this work, but they must be kept scrupulously clean ; the effect of temperature on stand development must also be borne in mind (page 67), as its effect on the length of development is, of course, magnified in proportion to the length of time taken.

Glycin is a particularly suitable developer for this work, and Hübl's formula is as follows:

Boiling water . .	4 oz. or 100 cc.
Sodium sulphite . .	2½ ,, or 62·5 gm.
When dissolved add	
Glycin . . .	1 oz. or 25 gms.

Then add, a small quantity at a time,

Potassium carbonate .	5 oz. or 125 gms.

This forms a cream, which should be well shaken up, and then diluted to the required extent; 1 oz., mixed with 80 oz. of water, with 80 minims of 10 per cent. bromide solution, will cause the image to appear in from 12 to 20 minutes, the total time of development being several hours.

A pyro-soda formula for development in about 30 minutes may be prepared as follows:

STOCK PYROGALLOL SOLUTION

Potassium metabisulphite .	60 grs. or 10 gms.
Pyrogallic acid . . .	1 oz. or 83 ,,
Potassium bromide . .	1 dr. or 10 ,,
Boiled water (cold) . .	12 oz. or 1000 cc.
A. Stock solution . .	3 oz. or 150 cc.
Boiled water . .	17 ,, or 850 ,,
B. Sodium sulphite . .	2 ,, or 100 gms.
Sodium carbonate .	2 ,, or 100 ,,
Water, to make . .	20 ,, or 1000 cc.

Mix equal parts of A and B, and dilute with four times the bulk of cold boiled water.

A somewhat elaborate formula for tank development is given by Tousey as follows:

Water	32 oz.
Anhydrous sod. carbonate	2 ,,
Anhydrous sod. sulphite	1¼ ,,
Ammon. bromide	30 grs.
Citric acid	30 ,,
Hydroquinone	60 ,,
Glycin	2 drs.
Metol	2 ,,
Pyrogallol	4 ,,

Dissolve the ingredients in the order given, and bottle the mixture in 6-oz. bottles, completely filled and tightly corked. For use add 6 oz. of the developer to ten pints of water.

X-Ray Films.—Celluloid films coated with X-ray emulsion are procurable, and are of considerable value where a small part is being radiographed, which is curved; hence their use in dental radiography. They are also used by some radiographers in connection with flexible intensifying screens for barium meal work, etc.

It seems doubtful whether either X-ray films or bromide papers will find much favour as compared with a plate for general use, except where some distinct advantage is claimed, as in the double-coated Eastman film, which is prepared with celluloid coated on both sides with emulsion; the under film, therefore, utilises what rays pass through the upper one, and the additive effect of

the two, it is claimed, makes reduced exposures possible. The 'Dupli-Tized' film certainly makes the use of two intensifying screens practicable, as the distance between the sensitive films is so small that distortion of the image cannot be but very slight. Tank development is recommended for these films, though they can be developed in an ordinary dish if desired.

A recent introduction of the greatest value for dental work is a film neatly bound between a thin card support and a thin sheet of soft tin ; [1] the complete film can be moulded into any shape, in which it remains, and when exposed is easily taken apart, and the coated celluloid film removed for development.

Before concluding this chapter, it may be useful briefly to summarise the faults more commonly met with in the development of X-ray plates, and their cause and prevention.

Fog.—This may be general or local. In the former case, the plates may have become fogged through keeping them too long in stock, in a damp or warm atmosphere, or by leaving about the dark room near the X-ray apparatus instead of in the lead-lined stock box. Local fog will develop usually from too much exposure of double-wrapped plates to ordinary light ; although the double wrapping is secure with careful handling, such plates should not be left about too long

[1] Buck's X-ograph dental films.

or in too strong a light. When plates are taken from a box and placed by the operator in double envelopes, care must be taken to avoid touching the film with the fingers or scratching them when inserting them in the envelopes, local fog and patches may be caused in this way. Fog is sometimes produced by a developer which has become contaminated with traces of other chemicals.

Black Spots.—These are generally small and often comet-shaped, and are most frequently due to particles of metol or other reducing agent having dropped from the air in the dark-room into the developer, or on the plates when drying ; larger black spots with dark centres are caused by not thoroughly dissolving all the reducing agent in the developing solution.

White Spots or Marks.—Minute air bubbles sometimes form on the film of the plates when the developer is poured over them. Ample developing solution should always be used ; the plate should be laid in the dish and the solution flooded over it with one 'sweep,' the dish being then well rocked. The plate should be removed and examined for surface bubbles after it has been in the developer a few seconds ; any bubbles can be removed by gently brushing them away with the fingers.

Uneven Development.—Uneven patches are invariably due to not rocking the dish sufficiently, or to using insufficient developer and so not

covering the plate completely when starting development. Peculiar striae and local patches of irregular shapes are also caused by letting the plate stand in the developer with insufficient rocking of the dish. These marks are often met

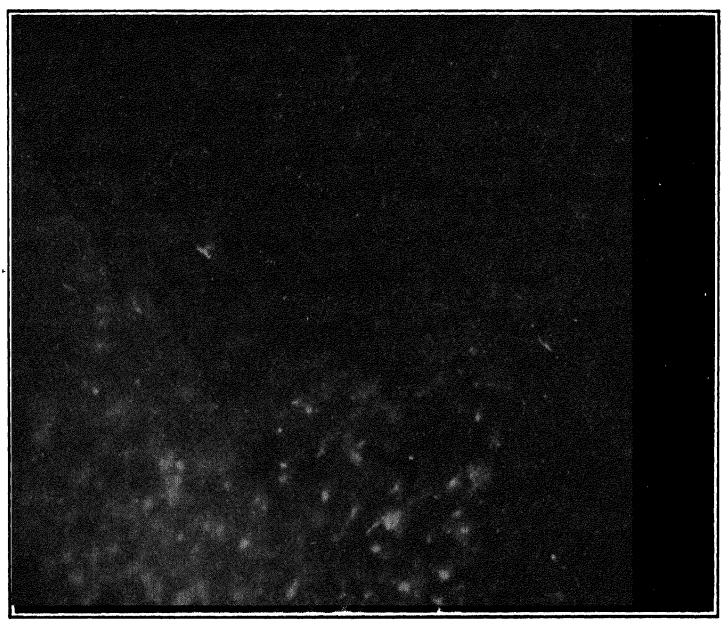


FIG. 27. Markings on negative caused by leaky plate-holder.

with, and are almost always put down, quite erroneously, to faulty manufacture of the plates.

Blisters.—These are formed, more particularly in hot weather, through the gelatine film leaving the plate in very minute patches, air then gets under the film and the gelatine expands and leaves the glass. They are caused by transferring

plates from a solution at one temperature to another solution at a different temperature. In hot weather the developing and fixing solutions will perhaps be at a temperature of 75 degrees or even 80 degrees F., and a plate may be taken from them and transferred to a dish of water from the tap which will be possibly only 55 degrees. This sudden change of 20 degrees or so is quite sufficient to cause blisters, hence the desirability of keeping the dark-room cool, or cooling the solutions, in very hot weather. The alternative is to transfer the plates after development direct to a hypo-alum bath, or to immerse them for five minutes, between development and fixing, in a formalin bath as follows :

Formalin (40 per cent. solution)	1 part.
Water	20 parts.

Frilling.—Plates are sometimes liable in hot weather, or with too much handling when wet, to frill at the edges. The trouble is more frequently met with along the *cut edge* of a plate—plates are sometimes coated in the double size, and cut into two or four afterwards. The use of a formalin or hypo-alum bath will prevent frilling.

Dichroic Fog.—Negatives sometimes appear of a reddish tint when examined by transmitted light, and green when looked at by reflected light. This fault is known as dichroic fog, and is generally due to a contaminated developer. A pyro-

ammonia or hydroquinone and caustic developer is most likely to make the trouble arise. The obvious remedy is to use fresh developer or to adopt a different formula.

Plate manufacturers, one and all, use the utmost care in making, testing, and packing plates, and it is very rarely that any of the troubles above outlined are due to any inherent faults in them. It should be recognised that the photographic plate is of an extremely sensitive character, and that the greatest care must be taken in its handling and manipulation in order to get consistently good results.

CHAPTER IV

Intensifier screens: their rôle in radiography—Methods of use and modifications needed in development—Their physical properties and applications.

THERE are several advantages in reducing the exposure in radiography to a minimum. The length of life of the tube is increased; any movement on the part of the patient is minimised; effects due to secondary rays are almost eliminated; danger to the patient of exposure is lessened; and so on. The early intensifier screens allowed exposure to be reduced by one-half or two-thirds, and were not of great practical value. These screens to-day, however, admit of a reduction in exposure to at least one-tenth the normal, so that in taking an elbow, for an example, where twenty seconds might be given with a small apparatus, only two seconds would be needed—and with the best intensifying screens, only a second, or 5 per cent. of the normal exposure. Their greatest use is probably in connection with apparatus of only moderate power for general work, and with high power apparatus for obtaining very rapid exposures of the heart, lungs, etc.

All intensifier screens used in military hospitals

were submitted before issue to a careful test for sensitiveness and general quality at South Kensington, so that the operator knew that his screen, at any rate, was not at fault. Intensifier screens have become an essential part of every X-ray equipment, so that all hospital operators have to deal with them, and in many cases voluntary but inexperienced assistants develop the plates exposed with them so that the subject of their use will be discussed at some length.

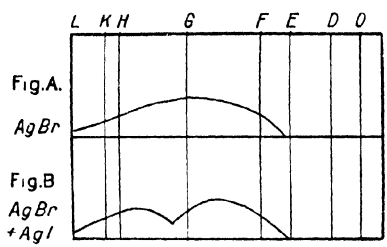


FIG. 28. Curves showing colour-sensitiveness of (A) silver bromide; (B) a mixture of silver bromide and iodide.

The screen consists of a thin, very flexible card support coated with minute crystals of calcium tungstate ($CaWO_4$); this substance occurs naturally as the mineral Scheelite, but when prepared by the manufacturers it is made by roasting the non-crystalline calcium tungstate under certain conditions until it assumes the crystalline form of Nature, when it fluoresces brightly on exposure to the rays. The fluorescence is of a blue-violet colour, and not sufficiently intense to admit of the screen being used for fluoroscopy. The blue-

violet rays possess a very high photo-actinic value, so that the image produced on the screen affects the photographic plate far more quickly than the X-rays themselves; hence the decreased exposure that may be given.

By suitable chemical treatment the tungstate may be made to give a more violet spectrum on excitation by the X-rays, or it may be made to give a bluer spectrum. If we photograph the spectrum of white light on an ordinary plate, and measure the density of the negative photometrically as described in Chapter II., for various wave-lengths, and plot a curve showing the relation between wave-length and density, we shall find that in general the maximum sensitiveness of the plate lies somewhere between the *G* and *F* Fraunhofer lines (see Fig. 28, A); by making a plate emulsion with a mixture of silver bromide and silver iodide—prepared separately, not emulsified together—a plate can be produced with two maxima of sensitiveness (see Fig. 28, B), one at H$\frac{1}{2}$G, and one at G$\frac{1}{3}$F approximately. Such a plate, if obtainable, would be ideal for present-day intensifier screens, as the spectrum of the fluorescent rays produced in the various makes of screens appears from spectro-photometric measurement to lie about these two regions.

Obviously the ideal intensifier screen, and plate combination would be that in which the spectrum of the screen fluorescence coincided with the region

of maximum sensitiveness to the spectrum of the plate employed. There is a tendency in modern screens and plates for this to be realised, and a new plate of this type is shortly to be issued.

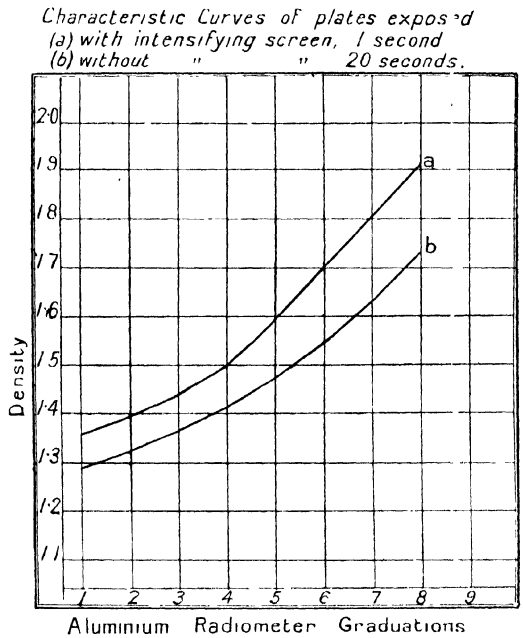


Fig. 29, showing the similarity in character of negatives obtained with and without an intensifying screen.

It is probably possible still further to increase the efficiency of present-day intensifier screens by specially sensitising the plates, just as 'orthochromatic' plates are sensitised for the green and yellow rays.

Many of the fluorescin, cyanin, and iso-cyanin derivatives impart distinct maxima of sensitive-

ness to a photographic emulsion, and by a suitable combination the plate could be sensitised to complement more or less exactly the fluorescence of one of these substances.

Two practical points which must be borne in mind in using intensifier screens are that the screen itself and the plate-holder or cassette must be kept scrupulously clean, and that the screen must be kept either in the cassette or in its case when not in use, in order to preserve its flatness. The surface of the screen is delicate, and should not be touched with the fingers, it should be brushed over with a soft, wide, camel-hair brush each time before use, and the cassette should be brushed out as well. The most careful and experienced workers seem to neglect these points, and 'pin-holes,' scratches, and marks appear in the negatives in consequence.

The screen is laid in the cassette, sensitive side uppermost, *i.e.* so that the uncoated side will face the rays during exposure. The plate is then laid upon it, the film of the plate being against the sensitive surface of the screen. The uncoated side of the screen is usually given some distinguishing mark so that no confusion may occur in hurried work in the dark-room; the back of the Sunic screen is marked with a large triangle. It is essential to have ample pressure between the screen and the plate, and a strongly made cassette with stout aluminium front is advised.

There are various types of screen and plate-holders, or cassettes, in use, and most of them are fitted with springs in the back which press the plate against the screen. If the front of the cassette is not perfectly flat, such as is the case when a cardboard or very thin aluminium front is used, which frequently buckles outwards, there will be uneven contact between plate and screen,

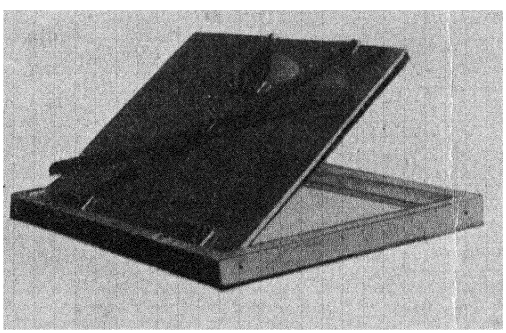


FIG. 30. A well-known make of cassette, or plate and screen holder.

and this will cause diffusion of the image, *i.e.* lack of definition, and great lessening of 'speed'; it is quite easy to make an intensifier screen vary as much as 50 per cent. in its reduction of exposure by varying the degree of pressure between its sensitive coating and the film of the plate. The greater the pressure can be made the shorter will be the exposure and the finer the definition. The crystals composing the active surface of the screen become *phosphorescent* under the influence of the

rays, and each one acts as a small light source, so that if the plate is not in firm contact, but separated by however minute a distance, a spreading action from each fluorescent crystal takes place.

Some cassettes are not fitted with spring backs, and if these be used, a pad made up of two or three sheets of blotting paper should be placed behind the screen and another behind the plate, so that when the cassette is shut, the screen and plate will be firmly pressed film to film.

This question of good contact and strong pressure is one of such great importance that it cannot be too much enlarged upon ; only a series of carefully conducted tests will show the full influence of and benefit from sufficient pressure.

Some text-books still recommend the early practice of loading the cassette so that the glass side of the plate faces the anticathode in exposure, with the screen *behind* the plate ; the rays have thus to pass through the plate before reaching the screen. This procedure was intended to minimise the effect due to the granularity of early intensifier screens and so obtain sharper detail in the negative. This method is not to be recommended with present-day screens, as it considerably lengthens exposure and gives no better results. The grain of a plate exposed without a screen, and through a Sunic screen, is shown in Figs. 31 and 32 respectively, from which it will be seen that the grain of the latter is prac-

tically as fine as that of an ordinarily exposed negative.

Granularity in the negative will, however, arise from *over-exposure*. As above pointed out, each crystal in the screen coating phosphoresces under the influence of the rays, and acts as a separate light source, and when unduly long exposures are given a spreading action takes place, greatly en-

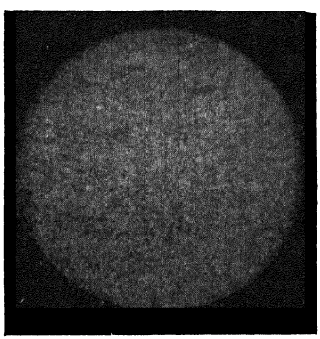


FIG. 31. Grain of X-ray negative.

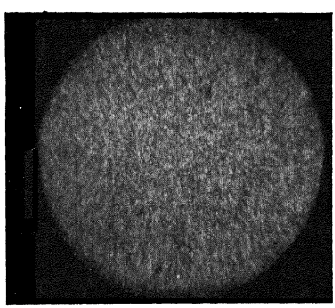


FIG. 32. Grain of X-ray negative exposed with intensifying screen.

larging its sphere of action in the film of the photographic plate.

A word may be said in reference to the sustained image noticeable with certain screens. Careful tests show that the phosphorescent image which can be seen on the intensifier screen immediately after exposure, which remains for some time with certain makes of screen, is of little value in forming the latent image in the plate; if the plate be left in contact with the screen for some time after a rather long exposure, the effect of the actual

exposure can be sometimes slightly increased, but the increase is small in comparison with what would be obtained from a very small increase in the exposure to the rays. It is doubtful whether the spectrum of the phosphorescence is the same as, or so active as, the spectrum of the fluorescence; in fact, it is certainly of longer wave-length in some cases and of less photo-actinic value. Some workers make a point of leaving the plate in the exposure case for about half an hour after exposure, and it is therefore of interest to point out that the end does not justify the means, and also that if a very short 'rest' be given to the screen after a long exposure there will be no danger of the phosphorescent image having any photographic effect on the next plate to be used.

It will have been gathered that to prevent granularity, over-exposure must be guarded against; this is also most necessary in order to obtain bright, vigorous negatives. Over-exposure with intensifier screens is the most frequent cause of failure, and of the complaint that there is a lack of contrast in the negative. An ordinary daylight photograph will appear weak or flat if over-exposed as is well known, and practically all failures with intensifier screens due to lack of vigour or contrast are caused through over-exposure.

That the degree of contrast or gradation obtained by using the screen is as good as that obtainable without it, may be seen from the two

curves shown in Fig. 29. Here *a* represents a plate exposed under a Benoist radiometer for twenty seconds to the X-rays, *b* a plate similarly exposed for one second through a Sunic screen, which reduced exposure by 95 per cent.

The two exposures were thus photographically equivalent, and it will be seen that the curves *a* and *b*, representing the scale of densities in the negatives (corresponding to different graduations of a Benoist radiometer) is practically identical. Both plates were developed with the same solution, but the plate exposed through the screen was given longer development; this is always necessary.

The X-rays, when used without a screen, penetrate and expose the entire film of the plate, and on development, as soon as the film has absorbed the developer throughout, development takes place throughout its entire thickness, *i.e.* every 'layer' of silver bromide particles is attacked nearly simultaneously by the reducing agent. When an intensifier screen is used, the exposure is chiefly superficial, the blue-violet rays responsible for the image are absorbed by the uppermost layers of silver bromide, development starts at the surface of the film, and has to work slowly downwards.

If a plate exposed through a screen develops as quickly as a plate exposed without a screen, it may be taken for granted that the former has

been over-exposed. The development factor is much greater, *i.e.* the ratio between the time taken for the image to appear and the time required for complete development.

It is important to determine what really is the factor by which exposure is cut down when using any given intensifier screen. Each time a new intensifier screen is brought into use it should be carefully tested for speed, and these tests should be carried out with the plates which are being used in practice. There is, and there will be likely, a great lack of standardisation both in intensifier screens and in X-ray or screen plates; we are only on the fringe of the physical chemistry of intensifier screens. The spectrum-sensitiveness of the different brands of X-ray plates and screen plates differs considerably, many radiographers use ordinary plates for screen work, and the spectrum-sensitiveness of different brands of ordinary plates also differs. Hence we cannot say that a certain intensifier screen will reduce exposure by any very definite percentage. It may reduce exposure by 95 per cent. with one make of plate, whereas with another brand of plate it may only reduce exposure by 92½ per cent. This means a variation of as much as 50 per cent. in the actual exposure with the screen.

A new screen is most usefully tested by photographing some part of medium thickness, such as an ankle, using rays of medium penetration. As

a first experiment: supposing it is known that without the screen an exposure of thirty seconds would be necessary, a screen exposure should be given of a tenth of this time—three seconds. If on development the exposure is found excessive, a further test should be made giving two seconds, and so on, until the actual intensifying factor is determined. This should be written in pencil on the back of the screen in case another operator has to use it at some future time.

It may be suggested that screens deteriorate with use, and that the reduction factor may therefore alter. The useful life of the sensitive material of a screen, as regards its intensifying properties, is usually far longer than that of the screen itself, owing to the inevitable mechanical damage attendant on frequent usage.

Screens made in the usual way show no marked signs of decay after many years' use with moderately hard X-rays, if carefully handled.

In other words, the modern intensifying screen is extremely stable, and the chief discrepancy that may appear to those who have not studied the matter is that the reduction in exposure is not so great when dealing with thick parts of the body as it is for very short exposures. It is not so readily excited by the harder rays, just as the ordinary X-ray plate is not so sensitive comparatively to hard rays as to soft. In order that any form of intensifying screen should function best,

it is essential that a maximum amount of the rays falling upon the screen should be absorbed, as by their absorption their energy is transformed into wave motion of greater wave-length, *i.e.* photo-actinic rays. It has been shown [1] that at least one-third of a beam of moderately soft X-rays passes through an intensifier screen; with many screens even more probably goes through unabsorbed. Further recent experiments have also shown that whereas an intensifier screen coated with a layer of tungstate a millimetres in thickness gives the maximum reduction in exposure with a soft tube, a thickness of $2a$ mm. gives greater reduction when the tube is worked harder, while as much as $3a$ mm. is the best for an intensely hard tube; in other words, a screen to be used for radiography of the hand or wrist may preferably be coated with as little as one-third of the crystalline material desirable for rapid exposures through the thick parts of the body.

In present routine work, however, only one type of screen is in general use.

A very considerable reduction in exposure may be made by the use of two intensifier screens, one on each side of the plate. Any rays that are not absorbed by the first screen and the plate therefore fall upon the second screen, so that the sensitive film is exposed from both sides simultaneously. The objection to this method is that

[1] Thorne Baker, *Journal of the Röntgen Society*, Sept. 1917.

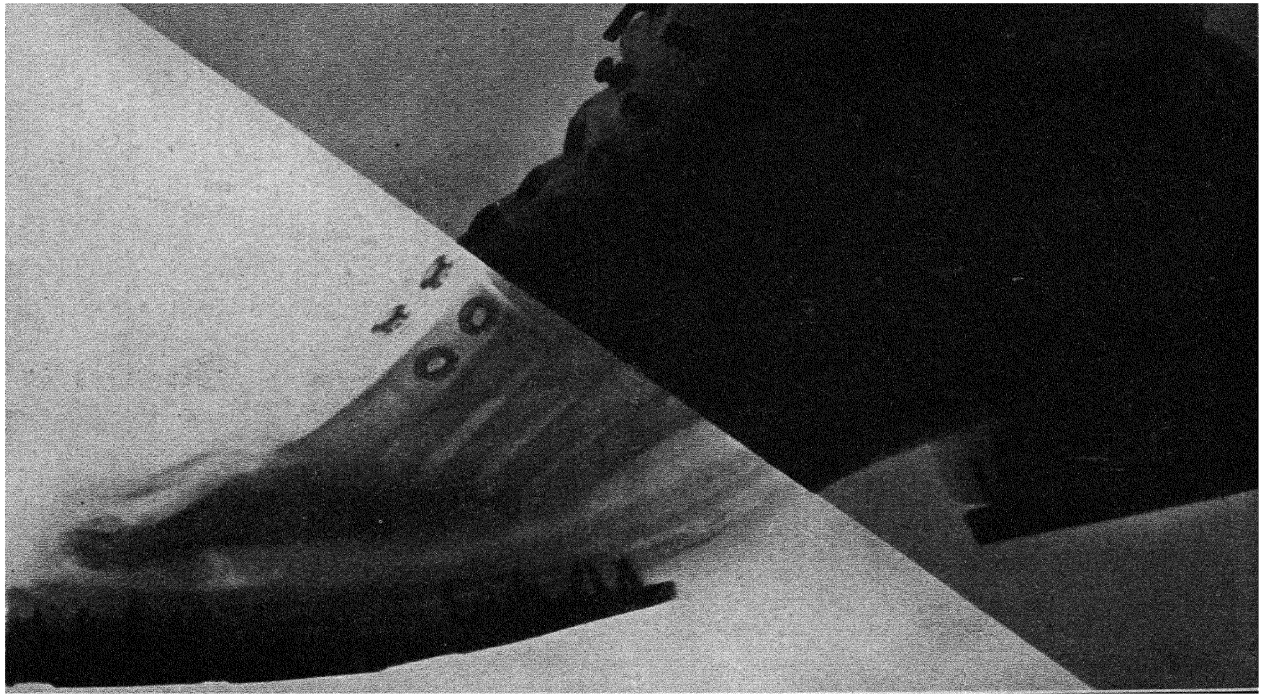


FIG. 33. Effect of the use of an intensifying screen ; the upper half of print was exposed without a screen, the lower half *through* a screen.

the effect from the second screen spreads a little, owing to its separation from the photographic film by the width of the glass plate, and that the definition is thereby impaired. This drawback can be overcome by the use of a celluloid film instead of a plate ; the reduction in exposure is nearly doubled by the method, which is therefore well worthy of adoption for extremely rapid work, more particularly since X-ray films of very high quality are manufactured now.

Some difference of opinion exists as to whether it is necessary to use an X-ray plate, when employing an intensifier screen. Some authorities state that they obtain as good results when using the screen, by using ordinary photographic plates, which are, of course, considerably less expensive. The Ilford Company make a special screen plate which is certainly superior to their X-ray plate for intensifier screen work. The matter depends largely upon the actual make of X-ray plate employed ; in our own experience it has been found generally preferable to use X-ray plates for screen work ; particularly where rays of greater penetration are used, which are not absorbed by, and do not excite, the screen *pro rata*, if the term may be used. This is a point which is worth the operator's while to determine for himself, as different conditions affect the result. If we use a plate which absorbs a great deal of the energy not already absorbed by the screen, it is reasonable

to assume that the latent image after exposure will be due to (1) the superficial exposure from the screen, plus (2) the exposure throughout the film due to the X-rays which have traversed the screen.

The great latitude of the X-ray plate, which is very heavily coated with silver bromide of a form peculiarly opaque to the rays, must always make it preferable for screen work on this particular ground. The grain, also, of ordinary plates is apt to be much coarser than that of a really good X-ray plate, especially of the faster varieties of the former, whereas the silver bromide in an X-ray plate has been precipitated in an excessively fine form in order to increase its opacity.

We come now to development, which should be carried out with due consideration to the very superficial effect of the exposure when a screen is used. The developer ordinarily used for radiography may be used, but it will be found an advantage to have about one-fourth less of the usual volume of water, and in addition to this extra concentration to restrain the action by the addition of two or three drops of 10 per cent. bromide solution to each ounce of developer.

Dr. Threlkeld-Edwards, maker of a well-known American intensifying screen, recommends an eikonogen developer for screen plates as follows:

provided with a waterproof surface, it is almost impossible to remove chemical splashes, and the greatest care should therefore be taken to keep the sensitive surface of the screen intact.

It may be remarked in conclusion that the definition in screen negatives can be considerably increased by increasing the distance between the anticathode and the plate-holder ; this, of course, prolongs exposure, but with a rapid intensifying screen the increase incurred will not be serious. In taking a knee, for example, with the anticathode 20 inches from the plate, the screen exposure might be, let us say, four seconds in a given instance ; by having 25 inches between anticathode and plate, we should only increase the exposure to six seconds, while greatly improving the definition in the negative.

CHAPTER V

Fluoroscopy—Character of visible image screens—Testing a fluorescent screen—Lead glass and glass spectacles—Screen stands—Protection.

THE only means of making a visual examination with the X-rays is by means of a fluorescent screen. The X-rays owe their discovery to the fluorescence of barium platinocyanide, so that the screen dates back to the earliest days of this branch of science.

If an electric discharge be passed through a tube which has been exhausted to less than a thousandth of a millimetre of mercury, rays emanate from the cathode which produce phosphorescence when they strike the glass. These rays travel under ordinary circumstances in straight lines, and if the cathode be made concave in form, the rays will converge to a focus, and a body placed at the focus will be raised to incandescence, even platinum being melted. If the tube be further exhausted, down to a pressure of only something like one-millionth of an atmosphere, and the cathode rays be converged on a target of some metal of preferably heavy atomic weight, X-rays are generated, which

travel outwards from the target, or anticathode. These rays, if they fall on certain substances, render them fluorescent, and hence by coating a screen of sufficiently large surface with such crystals, the whole screen glows uniformly when placed before the tube, except where the rays are stopped by bone, metal, or any substance opaque to them.

The phenomenon of fluorescence depends on the absorption of the invisible X-rays, and of readily fluorescent substances the author has found that compounds of the heaviest molecular weight give the least amount of contrast, but are the brightest for waves of very short length, *i.e.* the highly penetrating rays.

Fluorescence is only excited when the substance is under the influence of rays it can absorb ; when the rays cease, any after-effect is due to phosphorescence, which is a bad fault in a fluorescent screen. The physical action of fluorescence increases the absorption of the exciting rays up to a certain point, until a definite relationship is established between the intensity of the exciting rays and their absorption due to fluorescence. This property has an important bearing on both intensifying and fluoroscopic screens, as it indicates that there is a limit beyond which the screen cannot function any more intensely.

Wiedemann's theory that the molecule of a fluorescent substance exists in two forms, one

stable and the other less stable, and that the former absorbs the energy of the incident light, and is thereby transformed into the unstable form, emitting its absorbed energy as fluorescence by then spontaneously passing back to the stable form, has unfortunately been very largely investigated, and the modifications of his theory evolved, by researches made in organic compounds, and there is still much ground to investigate in the fluorescence of *inorganic* bodies.

Various substances possess the property of fluorescing under the influence of the rays. Apart from the platinocyanide of barium, calcium, strontium, and ammonium, etc., the silicate of zinc met with in Nature as Willemite, the double sulphate of uranium and potassium, Scheelite or calcium tungstate, and so on, all glow brightly when placed under the rays, and the colour in each case is different. Thus calcium tungstate is blue-violet, zinc silicate bright green, and the platinocyanides yellow or yellowish-green. Some of these substances occur in Nature in the most active form, others can be prepared in the laboratory, and considerable skill is required to obtain the best results. Thus zinc sulphide, prepared at a temperature of 650 degrees C., gives a blue phosphorescence when excited by radium rays, green at a higher temperature, yellow at still higher temperatures, while if prepared at over 1100 degrees C., the phosphorescing properties are

very poor.[1] Calcium tungstate, prepared by roasting a precipitate by mixing lime with sodium tungstate, fluoresces under the rays a violet colour which becomes bluer as the temperature is increased.[2]

The chemical formula of the salt used in making platinocyanide screens is $BaPt(CN)_4$, $4H_2O$. The platinocyanide molecule is allied to four molecules of water (H_2O) of crystallisation. This is a common property in salts, and by heating salts containing water of crystallisation, the water can be driven off, when the salt is said to be anhydrous. This water, in the case of barium platinocyanide, plays an important part in its physical properties, and it appears to be removed not only by heat but by pressure, and exposure to the X-rays themselves. The latter property is doubtless responsible for the gradual deterioration of the screens. But the fact that heat drives out the water, and the further fact that when driven out, the platinocyanide is no longer fluorescent, makes it very necessary to avoid placing a screen in too warm a place. We have come across cases where screens have been ruined by standing them against a hot-water radiator, the hot sections of the latter showing as parallel stripes in the screen. It was formerly advised that screens should be placed in

[1] MacDougall, Stewart and Wright, *Journal of the Chemical Society*, Aug. 1917.

[2] Thorne Baker, *Journal of the Röntgen Society*, No. 52, 1917.

strong sunlight when they become very yellow, to 'rejuvenate' them. Whether this has any good effect or not, it is highly dangerous, as the heat of the sun may have exactly the opposite effect.

Pressure has the same effect as heat, turning the platinocyanide a reddish-brown, and although most screens are now covered with lead glass, the screen may be put down on the table or bench on the top of some object, when the weight of the lead glass may force the object against the back of the screen and so transmit pressure to the crystals. It will thus be seen that a fluorescent screen should be handled with the greatest care, and it should not be exposed to powerful rays for unnecessarily long periods.

Damaged or deteriorated platinocyanide screens are now of great value owing to the platinum they contain, and should be returned to the makers, in order that the platinum may be recovered.

The quantity of barium platinocyanide crystals distributed over a given area of screen varies with different screens, but is now usually the minimum amount that will give sufficient brilliance. Too rich a coating is bad, as not only are the contrasts obtained less than with a moderate coating, but the definition is worse. The contrast obtained in the screen image is greatest when the rays are soft, and the tube should be worked as 'soft' as possible consistent with suffi-

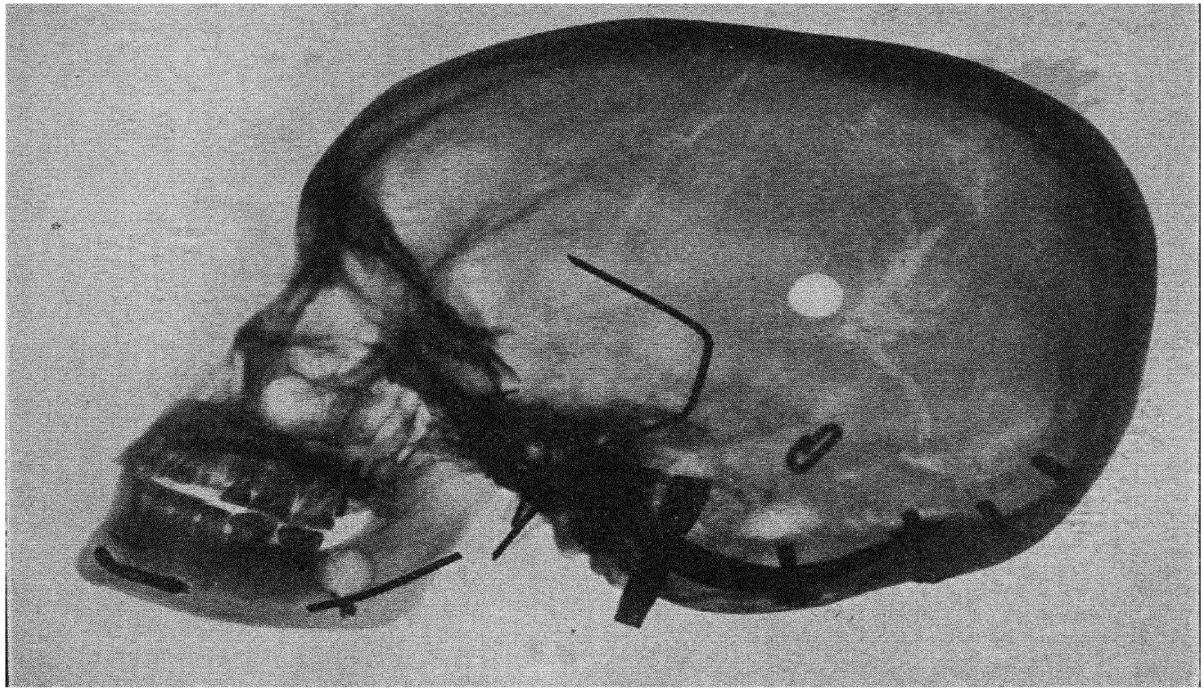


FIG. 34. Example of good radiograph ; a full exposure with the plate at a sufficient distance from the anticathode gives good detail throughout.

cient penetration; on the other hand, the distortion is reduced by having the screen as far away as possible from the anticathode, and should not if possible be nearer than 24 inches.

A screen may be tested for its power of definition by laying it on a couch (the tube being underneath), with an ordinary lead pencil under it; the lead of the pencil should show quite distinctly in the wood. Another useful thing is a piece of perfectly flat wire gauze, of about sixty-to-the-inch mesh, the wire mesh should show very crisply, and not be at all blurred or diffused.

The tendency of the image to remain on the screen after the rays have been stopped, due to *phosphorescence*, is another matter to be looked for in testing a screen. A good platinocyanide screen should not show this fault to any marked extent. Phosphorescence appears to be due to the presence of a minute proportion of foreign substance in the crystals—notably iron. It is much more marked in some crystals than others. Willemite, for example, exhibits this property in a marked degree, and requires most careful preparation before it can be used for the coating of fluorescent screens, that prepared artificially giving best results.

If a cross, circle, or some simple design be cut out of a piece of lead sheet, and placed behind a screen, the screen being placed about 15 inches from the anticathode of a tube run at about

2 milliampères, at a 5-inch alternative spark-gap, and the rays switched on for about a minute and then stopped, the pattern of the lead object will

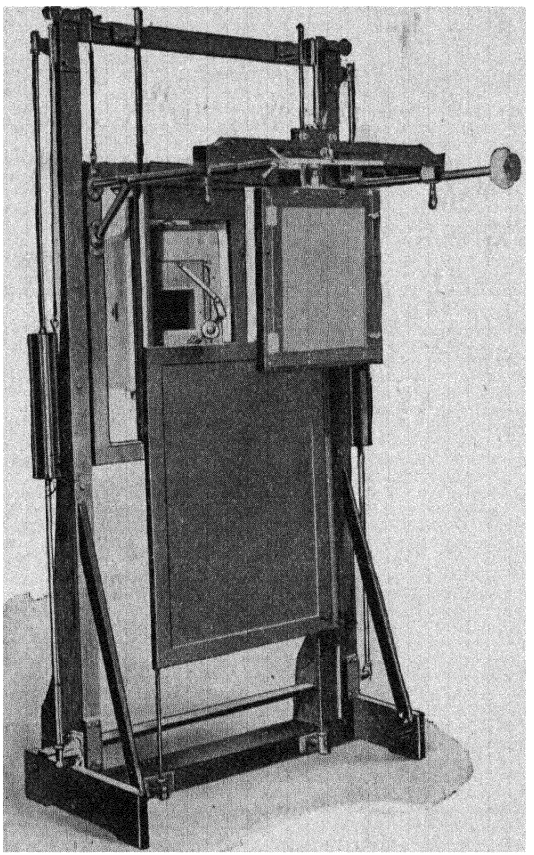


FIG. 35. Protected screening stand for fluoroscopy.

still be observed for a very short time on the screen, due to the phosphorescence of the exposed part of the screen. The image rapidly fades away —almost immediately with a good platinocyanide

screen—but it may take a second or two, or even more, with an indifferent screen. Although not a serious drawback, it is at the same time one which is better avoided. The author has prepared a zinc sulphide screen in which the image remains for nearly ten minutes after a brief exposure to the X-rays, with the object of enabling a very short exposure to the rays being given, the fluoroscopic examination being then continued at leisure from the phosphorescent image. The method is not yet practical, as the image is not sufficiently persistent.

It is important before making a screen examination to get the eyes thoroughly accustomed to the dark, and the fluoroscopic room should itself be perfectly dark. Five to ten minutes should be spent in the dark-room before the examination is attempted. Even then, unless the tube be fully enclosed in a light-tight box, a fluoroscope will be found an advantage, to shield off extraneous light. Spectacles have been made recently, of glass having the same transmission spectrum as the spectrum of the fluorescence rays, so that the light can be turned on without the eyes being much affected.

A device which is useful to enable the milliammeter to be seen without turning on the light during screen examination is also obtainable. This is a small vacuum tube run in series with the X-ray tube, which emits a pale violet light

just sufficient to illuminate the meter dial. When not required, it can be short-circuited by dropping

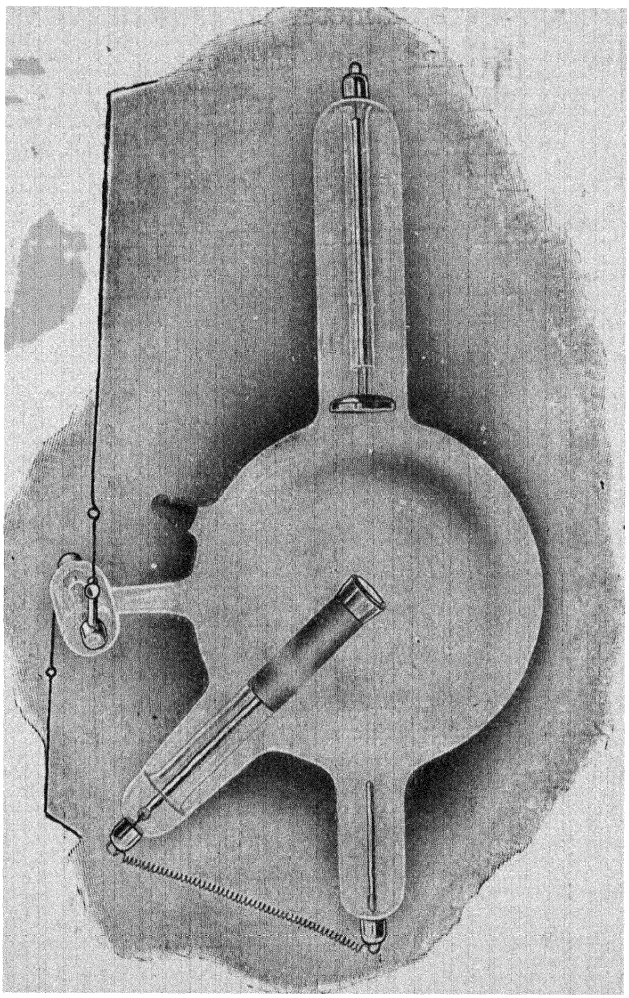


FIG. 36. Example of X-ray tube with softening device, the softer rays giving better contrasts in screen examination.

a hinged metal bar across the terminals. This is a very useful piece of auxiliary apparatus, as it provides just sufficient illumination to be com-

fortable while hardly affecting the eyes at all as regards the screen examination. It has also been found a useful plan to have the indicator and numerals of the milliameter coated with radium luminous compound, as the current passing through the tube can then readily be observed in the darkened room.

Protection.—The injurious effects of the rays must be carefully guarded against in fluoroscopic

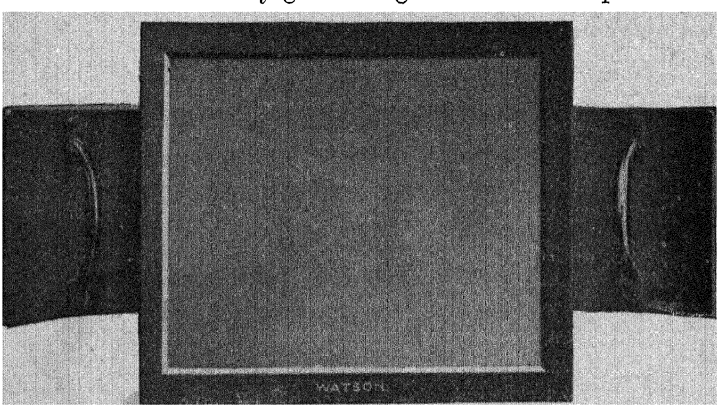


FIG. 37. Fluoroscopic screen with protected handles.

work, as the exposure to them is considerably more, as far as the operator is concerned, than it is when taking photographs. All fluorescent screens should be fitted with lead glass, and the lead glass itself should have passed a satisfactory test before being fitted in the frame of the screen. The great bulk of rays other than those directed upon the screen should, of course, be shielded by the use of a suitable tube box, but if the screen

be held in the hands, the frame should be fitted with protective metal handles such as are shown in Fig. 37.

An adjustable screen stand is seen in Figs. 35

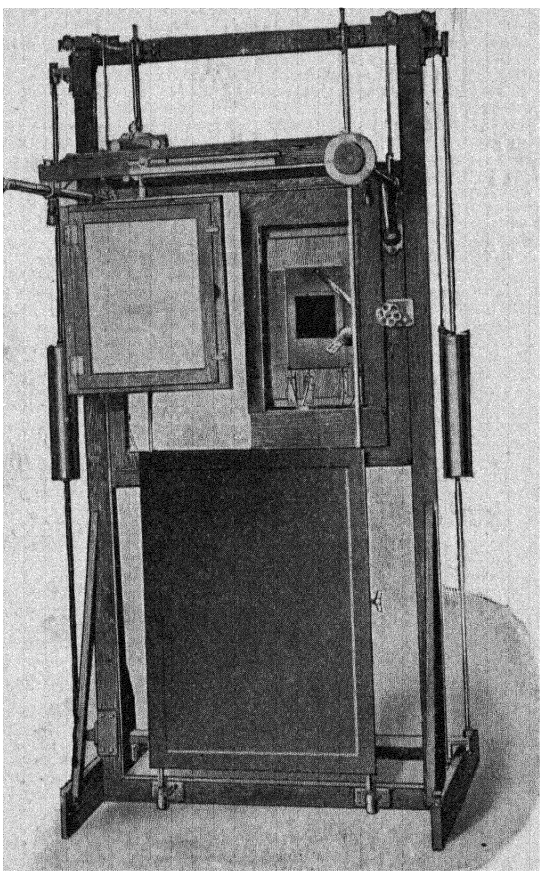


FIG. 38. Screen stand with adjustable rectangular diaphragm.

and 38. The screen can be raised or lowered by means of the handles, and through the use of counterpoises its movement is rendered very easy.

The width of the stand is such as to afford good protection to the operator. In some cases recently two sheets of lead glass have been fitted in the screen frame, thus considerably diminishing the exposure of the face and eyes to the rays. Lead glass spectacles can be used in addition. The disadvantage of lead glass is its imperfection, causing a certain amount of blurring of the image.

By the intelligent use of diaphragms placed in front of the tube, the definition, or more correctly, the contrast, in the fluoroscopic image can be considerably increased. The late Sir J. Mackenzie Davidson provides, in his localisation couch, a diaphragm in which a rectangular aperture can be readily modified in shape and size, so that the part under examination can be seen by itself, and confusion due to light from the whole of the screen avoided. Continental workers sometimes use small screens mounted like reading glasses with the same object in view, though these are not to be recommended.

At the time of writing platinum has reached such a high price that the purchase of a fluorescent screen is one which requires a good deal of thought, and the various materials which have been produced as a substitute for platinocyanide deserve consideration. Willemite, or zinc silicate, both natural and artificial, fluoresces a good green colour, but in most cases possesses the drawback that the image persists slightly, *i.e.* remains just

visible for a short period after the rays are stopped. It is claimed that these screens are superior to platinocyanide for bone work, whereas the latter are better for flesh work ; they are also unaffected by intense radiations, which certainly deteriorate platinocyanide in time.

Another compound, used in the Imperial screen, is an extremely heavy complex tungstate of cadmium, which has a very high molecular weight, and therefore absorbs the hard rays far better than platinocyanide ; the fluorescence is a bright bluish-green, and for thick parts of the body gives very fine definition and contrast. This screen is of especial value in the examination of materials, such as metal castings and parts, as it gives an image long after platinocyanide fails.

There is no gainsaying that whatever type of substitute for platinocyanide be adopted, a barium platinocyanide screen should be available in addition if possible ; conditions will be met with where each screen in turn proves superior, but for general medical work a platinocyanide screen need no longer be regarded as indispensable.

CHAPTER VI

Localisation by radiography—Stereoscopic radiography.

THE localisation of foreign bodies with the X-rays is an important branch of radiographic and radioscopic work, and is fully dealt with in practically all the medical treatises on X-rays; a number of appliances for localisation work are made by different firms, who also publish fairly complete details of their manipulation. It is not proposed therefore to give more than a brief account of the principles on which all localising methods depend.

If we draw two triangles, *ABC*, *DEC*, as shown in Fig. 39, such that *AC* is equal in length to *CE*, and *AB* is parallel to *DE*, and *AB* equal in length to *DE*, the two triangles will be exactly equal in every respect. If one triangle be smaller than the other, such as *FGC*, the two triangles are said to be 'similar.' The ratio between *AC* and *CG* is the same as the ratio between *BC* and *CF*, or between *AB* and *FG*.

Suppose now that *A* and *B* each represent a separate position of the anticathode of a tube, an exposure having been given on a plate with the tube in each position. If *C* represents a

foreign body such as a coin, in the patient, G will represent the image of it on the plate formed by the exposure with the anticathode at A, F the image with the anticathode at B.

Now we can measure the distance AG, *i.e.* the distance between the anticathode and the plate, and we know the distance AB—the distance we moved the tube between the two exposures; FG can be measured on the negative, and these three distances give us the necessary data to calculate the position of the foreign body C, relative to the plate FG, which, of course, rests against the patient. If we denote this distance CG by x, then AC will be $AG-x$, and

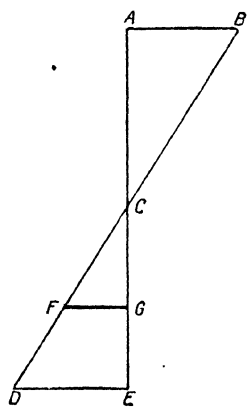


FIG. 39.

$$\frac{AG-x}{AB} = \frac{x}{FG}$$

by the law of similar triangles, or

$$x = \frac{AG \times FG}{AB + FG}.$$

Thus in x we find the distance of the foreign object from the plate by multiplying the distance between the anticathode and plate by the distance between the negative images of the object, and dividing the product by the figure obtained by adding together the distance through which the

tube was moved and the distance between the negative images.

In a couch designed for localisation work, the tube can usually be moved along a horizontal graduated bar; cross wires are provided which lie immediately over the plate, being sometimes attached to a wooden frame in which the plate can be placed; thus the image of the cross wires appears in the negative, and if the position they occupied be marked also on the patient, the location of the foreign body can be obtained with considerable accuracy.

The stereoscopic method of localisation involves taking two separate negatives, which can be examined by means of a stereoscopic viewing apparatus. In this work the operator must take pains to produce the two negatives of identical character. The tube should be carefully adjusted and should be running smoothly, and the two plates exposed as quickly as possible one after the other; it will be found a good plan to develop the two plates together, each in a separate dish with fresh solution, for the same time.

The stereoscopic negatives may be examined by means of a special pair of eyepieces, or with a double viewing lantern such as that shown in Fig. 40. The two mirrors in this apparatus are inclinable at an angle adjustable by a controlling screw handle, and can be tilted also as they are fixed on a universal joint. A little time elapses

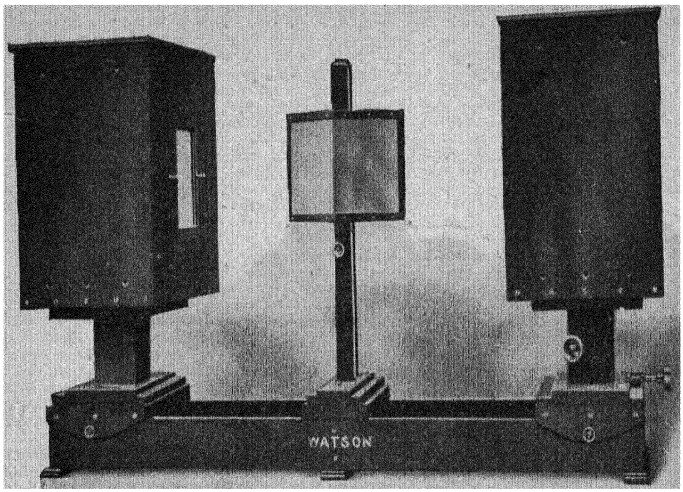


Fig. 40. Viewing apparatus for stereoscopic negatives.

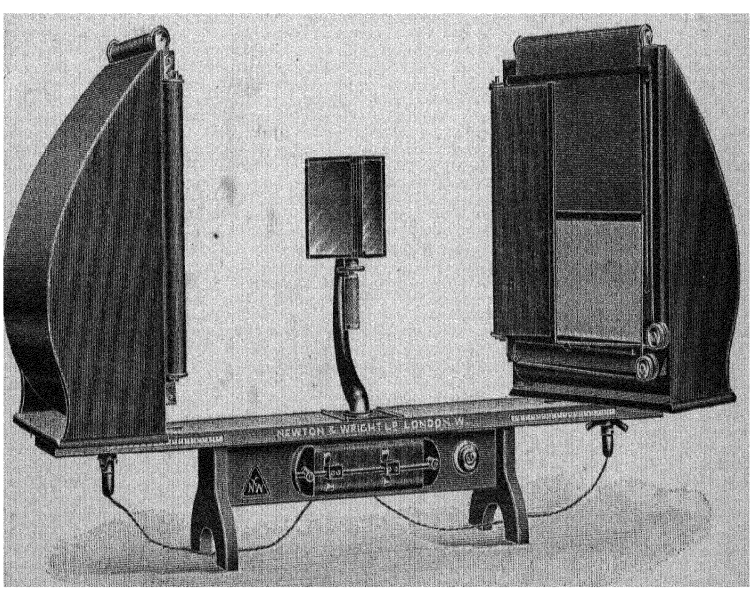


Fig. 41. Another type of viewing apparatus, showing the vertical and horizontal blinds for adapting to negatives of different sizes.

before the eyes recombine the two images, but when they do the subject is seen in perfect relief.

By making reduced prints from the negatives these may be examined with an ordinary stereoscope.

Sir J. Mackenzie Davidson pointed out [1] the great importance of maintaining complete immobility of the patient during the displacement of the tube and taking of the second photograph; otherwise an erroneous stereoscopic result may be produced, a piece of metal, for example, on the outside of the chest appearing as if inside, and so on.

In order to obtain stereoscopic images giving a true representation of reality, Hill and Barnard [2] point out that the tube shift must always be made equal to the distance between the eyes, and that the plates must also, in every case, be viewed at a virtual distance equal to that at which the radiographs were taken.

[1] *Proceedings Royal Society of Medicine*, April-May 1919.
[2] *Archives of Radiology and Electrotherapy*, Sept. 1919.

CHAPTER VII

The dark-room and its equipment—Illumination and safe-lights—Chemicals, their storage and use.

THE dark-room deserves a good deal of attention in radiographic work. In the earlier days of amateur photography development and printing had too often to be carried out in a cupboard or cellar or darkened attic, but where important work is to be carried on, and more especially where in hospital routine the surgeon often wants to examine a plate just as it has been developed, careful organisation and ample space are necessary.

The dark-room should not err on the side of smallness. Plenty of space should be available, good ventilation, and some means of heating such that a fairly uniform temperature, about 60 degrees F., can be maintained in cold weather. Order and neatness, combined with method, should be observed, and the strictest cleanliness; an ample stock of chemicals should be kept, and all bottles should be very clearly labelled in order that their contents can be readily distinguished in the dark-room light.

There are, of course, many instances where the conditions are far from ideal, and the work

must be carried on as best it can. This applied particularly to war work, where sometimes the available conditions were very unsuitable, but had to be put up with.

A diagrammatic sketch of a suitable dark-room is shown in Fig. 42, and it will be noted that the loading up of the intensifier screen cassette, or of the opaque envelopes, takes place at the begin-

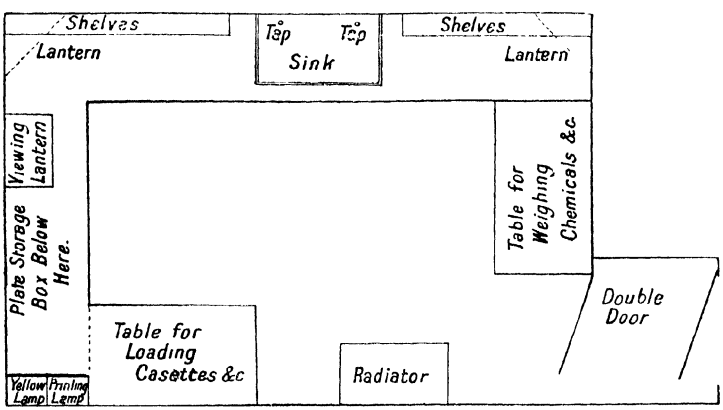


FIG. 42. Rough plan of radiographic dark-room.

ning of the bench space, development comes next, then fixing, hardening, and washing. Space is provided further on for printing, etc., so that a complete cycle of operations can be carried on in orderly succession. A table of ample dimensions is provided, with drawers, for such work as weighing up chemicals and making up solutions, for intensifying negatives or carrying out 'after processes,' and two separate lanterns are sug-

gested, one fitted with a green safe-light for development, the other with a yellow light for bromide or gaslight printing. The switch for white light is placed some little distance from the switches for the lanterns in order to avoid any danger of the former being turned on inadvertently while plates are exposed. Some shelves for chemicals should be provided, and an ample supply of dishes, troughs, etc.

The sink also should be of ample size, and it should preferably be of the deep pattern—6 to 9 inches in depth; this will save a good deal of splashing on the bench, and for the same reason an anti-splash nozzle should be fitted to the tap; a good substitute for these nozzles is a short length of rubber tubing, about 3 inches, attached to the end of the tap.

Ventilating and heating both require attention, the former more particularly where the routine work possibly demands the presence of an operator in the dark-room for some hours daily. As will be seen in the chapter dealing with development, the temperature of the solutions and dishes has a most important influence on the work, and a temperature of between 60 and 65 degrees F. should, if possible, be maintained not only to prevent delay in development when solutions are cold, etc., but to maintain uniformity in the routine work. It is so easy to mistake the effects of low temperature for under-exposure, so difficult

to keep proper control over the technical results in hot weather, that where at all possible this matter should receive really careful attention. The heating is not easy on account of the light it involves, unless hot-water pipes or radiators are available; but an electric radiator can be employed if the current consumption is not of material consequence, as this can be fairly easily screened, or even switched off during development.

Electric fans are unwise on account of their drawing small particles of dust in the air currents; frequently developers have to be weighed up in the dark-room, and it is not uncommon for plate makers to get complaints of small black specks which are entirely due to particles of metol which have been carried by the moving air and deposited upon the plates either before or during development. If the ventilation cannot be arranged by ordinary draughts, the only alternative is to have a window which can be opened whenever the dark-room is not in use; for this reason it is better not to have windows boarded in, but to paint the glass with some good type of dead-black varnish, or better, to use light-tight shutters.

A squeegee is a useful article for wiping over the benches or tables, otherwise they should be frequently washed. Any splashes of chemicals dry in time, and leave a dry chemical residue which is sure to become disintegrated or be wiped with the sleeve, and so give rise to chemical particles

which contaminate the air and cause troubles in the plates. It is astonishing how many faults develop in this trivial way, even amongst careful and skilled workers; the author has had many years' experience in plate manufacture, and through dealing with so-called plate defects and tracing them to their causes, has found, as all other plate makers will agree, that in at least seven cases out of ten spots and markings in X-ray plates have originated from foreign matter in the dark-room.

Dark-rooms usually get well filled with a variety of chemicals and apparatus in course of time, but as a guide to the first instalment of necessary sundries the two following lists are suggested, and in the case of the chemicals, suitable amounts of each are given. Many chemicals deteriorate on keeping, so that it is not advisable to lay in too large an amount of them.

Dark-Room Apparatus:

1 porcelain or other dish 20 in.×16 in.
1 ,, ,, ,, 18 in.×15 in.
3 ,, ,, dishes 15 in.×12 in.
3 ,, ,, ,, 12 in.×10 in.
2 ,, ,, ,, 10 in.×8 in.

3 grooved porcelain troughs for:

1. Fixing.
2. Hardening.
3. Washing.

1 40-oz. cylindrical measure.
1 20-oz. ,, ,,
1 4-oz. ,, ,,
1 500-cc. ,, ,,
1 250-cc. ,, ,,
1 100-cc. ,, ,,
1 2-drachm and 1 25-cc. measure.
Lantern fitted with green (or red) safe-light.
Lantern fitted with orange or yellow safe-light.
Filter funnels, 8 or 10 in. in diameter, filter papers and filter funnel stand.
Low power magnifying-glass.
Scales and weights.
Squeegee.
Thermometer.
Dark-room clock.
3 'Winchester quart' bottles, some 40 oz., 20 oz., and 10 oz. bottles; some of these should have glass stoppers.
1 packet of gummed labels.
1 pair forceps.
One or two plate lifters.
2 large camel-hair brushes.

Chemicals:

½ lb. metol or metol substitute.
1 lb. hydroquinone.
7 lbs. sodium sulphite (crystals).
7 lbs. sodium carbonate (crystals).
2 lbs. potassium metabisulphite.

1 lb. potassium hydroxide.
28 lbs. sodium thiosulphate (' hypo ').
2 lbs. alum (potash).
1 lb. chrome alum.
15 grs. gold chloride.
½ lb. ammonium sulphocyanide.
20 oz. hydrochloric acid.
¼ lb. potassium bromide.
4 oz. mercuric chloride.
½ lb. ammonium chloride.
20 oz. ammonia (·880).
Distilled water.

In addition, some form of viewing lantern will be required. This usually consists of a box con-

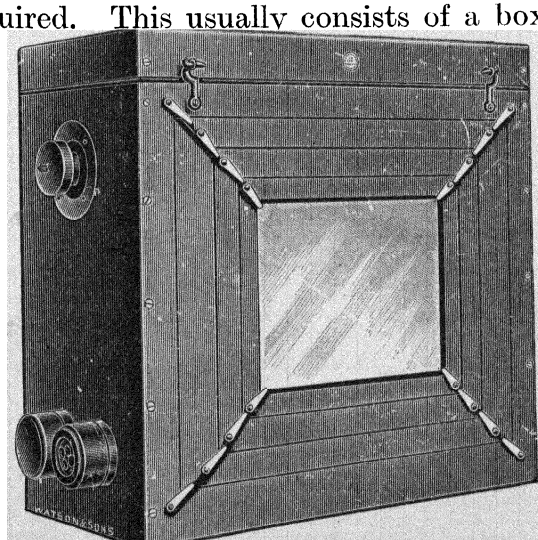


FIG. 43. Viewing lantern.

taining an electric lamp, with ground glass front, and a ledge on which to rest the negative being

examined. It is a great advantage if the front be fitted with adapters, whereby all white light can be excluded and the viewing aperture made the exact size of the negative; Newton and Wright, Ltd., make an excellent lantern of this type, with two roller blinds, one drawing vertically downwards, the other horizontally across, whereby by adjusting the blinds with milled heads the aperture can be made of any desired size.

Safe-lights.—There are many different types of dark-room lantern, some provided with ruby and yellow glass, or some kind of material, but the bulk of lanterns in use are of a standard pattern, and are fitted with a 'safe-light,' *i.e.* a stained gelatine film glazed on both sides, made generally by staining a glass plate coated with gelatine and mounting or covering it, like a lantern slide, with a plain glass in order to protect the film. Some lanterns are fitted with a cell or trough which is filled with coloured liquid, but such liquids are bound to evaporate and require attention.

The standard type of dark-room lamp is fitted with a safe-light 10×8 inches in surface, and has a reflector so arranged that a beam of more or less parallel rays illuminates the bench; the lamp itself is concealed, so that no direct rays fall upon the plate. A section of the lamp is shown in Fig. 44, and it will be seen that all direct rays

from the lamp are avoided. As already suggested, it is convenient to have a second lantern fitted with a yellow glass for use when making bromide prints from the negatives.

X-ray plates are not usually so sensitive to white light as ordinary photographic plates, so that one can generally have a fairly brilliant light in the dark-room, and if a green safe-light be used instead of a ruby glass, the dark-room work becomes far more pleasant, and the illumination can be so brilliant that one wonders at first how it can be safe.

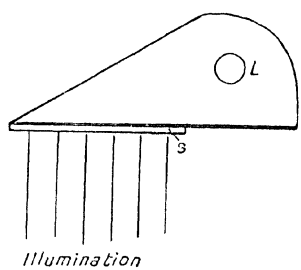


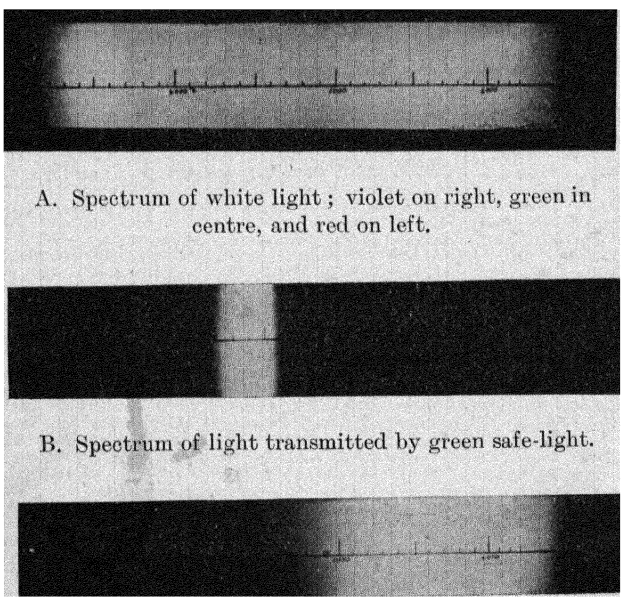
FIG. 44.

There are several makers of safe-lights — Sanger Shepherd and Co., Imperial, Ilford, Kodak, Wratten, etc.—and the price for the 10×8 in. size is only a few shillings. The reader may feel inclined to try his hand at making his own, and in this event the following particulars are given.

As a preliminary, however, we show in Fig. 45 two photographs of the spectrum of white light taken (A) on a panchromatic plate; (B) on the same make of plate, the light passing through a green safe-light before reaching the slit of the spectroscope.

The blue-violet rays are registered at between 4000 Ångstrom units and about 4800; the green

rays occupy the position between, roughly, 4800 and 5500; the yellow rays 5500 to 6000, and the red rays beyond 6000. It will be seen from (C) that the plate is only sensitive to rays up to



A. Spectrum of white light; violet on right, green in centre, and red on left.

B. Spectrum of light transmitted by green safe-light.

C. Spectrum as recorded by X-ray plate, showing that it is unaffected by the rays passing through the green safe-light.

FIG. 45.

about 5300, *i.e.* to the violet, blue, and bluish-green rays. Obviously, therefore, if we expose a plate to green rays beyond 5600-5700, or to yellow or red, it should not become light-fogged. It will be seen from (B) that the safe-light used transmits only the greenish-yellow rays at about 5700; much commercial glass which appears

green or red to the eye actually transmits blue or violet rays in addition, and the greatest care, therefore, should be taken before using any coloured glass purchased of a glazier to test it photographically, in the manner described later, before trusting to it to illuminate the dark-room.

The easiest way to prepare a safe-light is by fixing a couple of unexposed plates in plain hypo solution, then thoroughly washing and drying them, and when dry, staining the films one by means of an aurantia, the other with a naphthol green solution, and binding the two together (when dry) film to film.

The solutions are as follows:

1.	Aurantia . . .	1 gm.
	Water . . .	150 cc.

Shake up thoroughly and filter.

2.	Naphthol green . .	2 gms.
	Water . . .	200 cc.

Shake up thoroughly and filter.

The dry fixed-out plates are stained in these solutions until in one case the film is a fairly deep orange and in the other case a moderately deep cabbage green. One or two filters of each kind should be prepared, one darker than another, and then a light and a dark pair can be bound together, and each pair, *i.e.* each complete safe-light, tested for safety with one of the X-ray plates actually in use.

In Fig. 46 *F* represents the safe-light to be tested, and 18 to 24 inches away is an ordinary dark slide, loaded with an X-ray plate, and the shutter half down, so that half the plate (*a*) is in darkness while the other half (*b*) is exposed to the green rays of the lantern. An exposure of one to two minutes should be given. On development there should be no fogging of the exposed half (*b*) of the plate. If exposure to the rays should produce fog, the safe-light will not be

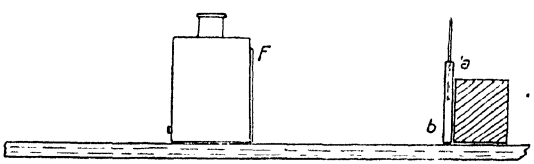


Fig. 46. Method of testing a safe-light.

'safe,' and if it has been prepared by the reader, he should use more deeply-coloured glasses. If the safe-light be a purchased one, and it has faded slightly from continued exposure to the warmth of the lantern, it should be at once replaced.

Chemicals.—The list of chemicals suggested on page 119 for use in the dark-room does not by any means embrace the whole of the chemicals that may be required for radiographic work; many radiologists, for example, use pyrogallol or glycin for development, or prepare the acid fixing bath with sodium bisulphite instead of potassium meta-

bisulphite, or use formalin for hardening the film in place of chrome alum, etc.

It is not necessary to keep in stock more than is actually required for making up the formulae employed, but it is a great convenience to have most of the items included in the list given.

Care too should be taken to use chemicals of pure quality, as a good many troubles in development can arise from unsuitable ones. Sodium sulphite, Na_2SO_3, for example, if kept in a paper packet or badly corked bottle, will gradually take up oxygen from the air and turn into sodium sulphate, which is useless as a preservative (p. 59).

Developing agents, such as metol, etc. should be kept very carefully corked or stoppered; metol and metol-substitute must be kept in dark green or brown bottles, or tins, as light decomposes them.

Caustic soda and potash readily combine with moisture and *deliquesce*, and must be kept tightly corked. If a bottle is put away for any length of time a little wax should be run over the cork.

Sodium carbonate should be bought of the best quality, as an inferior salt may contain caustic soda. Pure anhydrous sodium carbonate is frequently used, while some makers of developing powders use the monohydrate salt. The following are the chemical formulae for the various salts,

and the respective amounts of each necessary to produce the same result:

Anhydrous sodium carbonate	Na_2CO_3	1
Monohydrate sodium carbonate	$Na_2CO_3H_2O$	1·17.
Sodium carbonate crystals	$Na_2CO_310H_2O$	2·76.

Although washing soda is often recommended for use as sodium carbonate its usually caustic character makes it highly undesirable for X-ray work.

Great care should be taken to keep all bottles in the dark-room clearly labelled, and the solutions in use for developing, fixing, etc. should be kept in the dark-room near the sink, and the stock chemicals apart by themselves.

Stock Solutions.—It is sometimes useful to keep a few stock solutions, with which a developer or other bath can be compounded quickly without resorting to the scales. Thus pyrogallol, gold chloride, etc. are typical examples. Potassium bromide is sometimes added to a developer during development and is generally kept for this purpose as a 10 per cent. solution. One ounce is put in a measure and sufficient distilled water added to make ten fluid ounces; the stock solution is then bottled; if required for making up a developer, for every grain wanted we should use 10 minims of solution, or for every gram, 10 cc. Gold chloride is sold in 15 grain tubes, and a tube may be carefully broken in a small clean mortar

and 15 drachms of distilled water added; the stock solution should be kept in the dark. For each grain required we should obviously take 1 drachm of solution. Where metric measures are used, the contents of the tube may be dissolved in 100 cc. of water and 10 cc. used for each 0·1 gram required.

Chemicals which are used in bulk should not be made up as stock solutions. Thus while sodium or potassium hydroxide may be so kept, sodium carbonate crystals should be weighed up as required.

Photographic formulae are unfortunately given in a most liberal way in both English or Metric measures, and very often where the two sets of figures are given side by side, one set is not the equivalent of the other. It is to be hoped that in due course the metric system will be adopted entirely, which will save a good deal of confusion. At present it is almost advisable to keep two sets of weights and measures in the dark-room; it saves a good deal of trouble and calculation. But it will be found an excellent plan to keep a dark-room note-book, and when time permits translate all formulae in English measures to metric, so that the latter may be adopted as a matter of routine.

A table is given in the appendix setting forth equivalents of the English weights and volume.

CHAPTER VIII

Intensification and Reduction

X-RAY negatives which are under-exposed, or those which are over-exposed and under-developed, may be greatly improved by intensification. Many negatives which may answer for diagnosis may also be much improved for printing purposes, or for more detailed examination, by intensification or reduction.

The former is a process by which the silver image is built up, or reinforced, by the addition to it of further insoluble opaque compounds. One of the most usual methods of intensifying a fairly normal, but weak, negative, is with mercury. Mercuric chloride combines with the silver of the image to form a double mercurous-silver chloride:

$$Ag + HgCl_2 = AgHgCl_2,$$

and the double chloride blackens to an intense deposit on treatment with ammonia or sodium sulphite, or on redevelopment with a ferrous oxalate developer.

It is absolutely necessary to effect complete removal of the last traces of hypo from the film

prior to intensification, and very thorough washing should be given to a negative before treatment. Practically all the common failures in intensification are due to incomplete washing. Certain compounds, particularly persulphates, are useful for this purpose, converting any traces of hypo into a harmless and extremely soluble compound; these are known as 'hypo eliminators,' and their use greatly accelerates its removal, although they are not necessary if sufficient washing be given. The persulphates are usually employed for this purpose, and are supplied under various trade names.

The negative is first bleached in a solution of:

Mercuric chloride .	150 grs. or 10 gms.
Ammonium chloride .	150 grs. or 10 gms.
Water . . .	7 oz. or 200 cc.

The plate is left in this solution (which is intensely poisonous) and well rocked, until the film has become consistently white. It is then removed and washed in running water for at least fifteen minutes, and then redeveloped by immersion in either of the following solutions:

1. Ammonia (·880) .	1 oz. or 30 cc.
Water . . .	10 ,, or 300 ,,
2. Sodium sulphite .	1 ,, or 30 ,,
Water . . .	8 ,, or 240 ,,

It rapidly turns black again in either of these baths, and when completely redeveloped, it is again well washed in running water, and dried.

This treatment gives intensification very fairly in accord with the original gradation of the negative. Fig. 47 shows a radiograph of an ankle, cut in two, the lower half being intensified with mercury and ammonia. There are processes, however, by which we can

(1) increase the contrast in the negative, or
(2) increase the details, or half-tones, and diminish the very dense parts of the image.

The first process is carried out by first reducing the negative in a bath which attacks the feeble parts of the image in preference to the dense parts. This is the ferricyanide reducer mentioned on page 133. It should be used rather stronger than it would be in the ordinary way, *i.e.* of a deeper yellow colour. When the half-tones, or least exposed details, begin to become perceptibly reduced, the negative should be taken out of the solution, and thoroughly well washed in running water for half an hour. It can then be at once bleached in the mercuric chloride bath already given, and subsequently redeveloped with either ammonia or sodium sulphite.

Mercuric Iodide Intensifier.—This is a one-

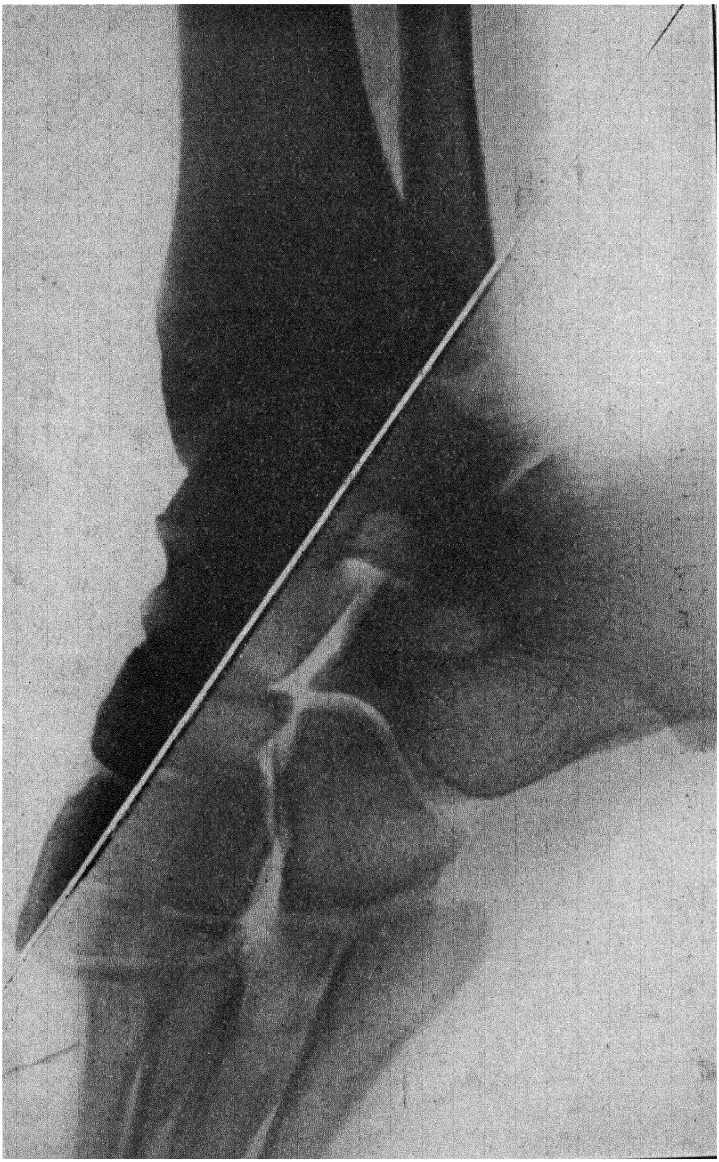


FIG. 47. The lower half of the above negative has been intensified, showing that by intensification a good radiograph can be produced from an otherwise useless negative.

solution intensifier, due to Lumière, and is made up according to the following formula:

Mercuric iodide	45 grs. or	3 gms.
Sodium sulphite (anhydrous)	440 ,, or	29·3 ,,
Cold water	10 oz. or	300 cc.

This should be kept in the dark. The negative is placed in the solution until sufficiently intensified, and then washed and placed for five minutes in a 5 per cent. solution of sodium sulphite, then washed and dried.

Uranium Intensifier.—This is also a one-solution bath, prepared as follows:

Uranium nitrate	96 grs. or	6 gms.
Potassium ferricyanide	96 ,, or	6 ,,
Water	10 oz. or	300 cc.
Glacial acetic acid	5 drs. or	20 ,,

Dissolve the uranium salt in half the water, the ferricyanide in the other half, then mix the two, and add the acetic acid. Remove the negative from the bath rather before intensification is complete, and wash it well.

One of the best and most convenient methods of intensification for radiographic work is the chromium process of Mr. C. Welborne Piper. The negative is first bleached in a solution of

Potassium bichromate	30 grs. or	2 gms.
Hydrochloric acid, pure	15 min. or	1 cc.
Water	3 oz. or	85 cc.

The bleached plate is well rinsed, and then redeveloped with an amidol developer, conveniently prepared as follows:

Sodium sulphite . .	1 oz. or 30 gms.
Water	10 ,, or 300 cc.

Dissolve, and add

Amidol	60 grs. or 4 gms.

The process can be repeated if desired, until intensification is as great as is required.

Reduction.—This operation is necessary when a negative has been so much developed that the details are too dense, and cannot, therefore, be seen clearly, or easily printed. It is also to be recommended in certain cases before intensifying, as already explained. The simplest method of reduction is by means of ferricyanide, which converts the silver image into silver ferricyanide, which is soluble in hyposulphite. A plain fixing bath to which has been added the necessary amount of potassium ferricyanide thus provides the reducing solution:

A stock solution of

Potassium ferricyanide	96 grs. or 5 gms.
Water . . .	4 oz. or 100 cc.

should be kept in the dark-room.

A solution of two ounces of hypo to half a pint of water (*i.e.* 10 per cent. solution) should be taken and sufficient of the ferricyanide solution

added to turn it a lemon yellow colour. The negative is placed in this bath and the dish gently rocked. The plate must be carefully watched, and constantly taken out and examined to see what reduction has been effected, and it must be removed rather before the necessary reduction has been reached and thoroughly washed in running water.

It frequently happens that a negative is very dense in the most exposed parts while the half-tones are good; this type of negative results from giving prolonged development to an under-exposed plate. In this case we must aim at reducing the dense parts without unduly attacking the half-tones. This can be done by using ammonium persulphate ($Am_2S_2O_8$), which has a selective action, and attacks the densest parts first.

The solution used is

Ammonium persulphate .	30 grs. or 2 gms.
Water	$3\frac{1}{2}$ oz. or 100 cc.

The plate must be taken out of the bath before the desired amount of reduction has been reached, and the action of the persulphate checked by transferring it to a 10 per cent. solution of sodium sulphite for two or three minutes; it is then washed as usual.

This method is particularly useful where an under-exposed long-developed negative is to be subsequently intensified.

Yellow or Green Stain.—A yellow or green 'fog' or stain over the plate, often appearing only locally, is sometimes met with. This can usually be removed by soaking the plates for several hours in a bath of:

Water	100 oz.	or 1000 cc.
Alum (potash)	5 „	or 50 gms.
Citric acid	1 „	or 10 „

This trouble is generally met with in winter time, but is not very common.

A yellowish stain which is also met with occasionally, especially with stale plates, can be removed by gently rubbing the film with a wad of cotton wool moistened with methylated spirit. Care must, of course, be taken not to rub too hard and so cause abrasion of the film. A solution of thiosinamin 2 parts, citric acid 1 part, and water 160 parts may also be used in cases of obstinate stain.

The use of an acid fixing bath, however, greatly minimises the likelihood of yellow stain making its appearance.

CHAPTER IX

Technique of the photographic print—P.O.P., Gaslight and Bromide papers—Carbon printing.

For the purpose of diagnosis as well as of reference it is more often than not necessary to make prints from X-ray negatives, and some makers of photographic paper have gone so far as to prepare special papers for this work. There is considerable choice in the matter of papers for printing, and some details of their use will be given in this chapter.

In certain cases it is desirable to make a print which can be kept for reference and must be permanent in character. There are only two types of paper which can be said to be permanent—platinotype and carbon. The latter is more suitable than the former for X-ray work, but the manipulation is nothing like so simple as in the case of the so-called silver papers; it is nevertheless strongly to be recommended where absolutely permanent prints are desired.

Of the silver papers there are three types:

1. Known as printing out paper, or more generally, P.O.P. This is prepared by coating

pure raw paper with a mixture of silver chloride and some organic silver salt with free silver nitrate. It is printed in daylight, and has the advantage that the progress of the printing can be watched, as well as the after-manipulation being carried out in ordinary light.

2. Known as gaslight paper, for the reason that it can be worked in weak gas or electric light in the dark room. It is a paper which requires development, but is so little sensitive that it requires a few seconds' or minutes' exposure a few inches away from an ordinary burner; it can be manipulated a few feet away from the same burner without danger of fogging.
3. Known as bromide paper; this is considerably more sensitive, and requires only a few seconds' exposure, and in consequence must be handled in yellow or green illumination.

P.O.P.—The great advantage of this process is that the most exquisite detail can be obtained, and it is thus eminently suitable for printing negatives containing fine detail, such as the osseous structure of the hand, ankle, foot, and so on. It is well to note that a more vigorous image will result from printing in a weak light, such as a north light, or a skylight on a cloudy day.

Where a negative is dense or hard in character the best result will be obtained by printing in direct sunlight, when the result will be comparatively flat.

A point worthy of mention in dealing with large negatives is the advantage of placing several thicknesses of soft paper or blotting paper behind the P.O.P. in the printing frame, so as to ensure good contact between the negative and the surface of the paper.

P.O.P. is made in glossy and matt varieties, but the former only is suitable for this work. Printing should be carried out a little deeper than the finished picture is to be, because the image loses somewhat in toning and fixing. Many operators like using a combined toning and fixing bath, on account of its simplicity, and where this is done a little extra depth should be given to the print as it loses more than in the case of separate toning and fixing. When separate toning and fixing are given (which gives the more permanent results), the print first requires a preliminary washing in order to remove any free silver nitrate and acid preservative from the film. If several prints are washed together in a dish in ten or twelve changes of water, or in running water, care should be taken frequently to separate them so that the water can act on each print thoroughly. Fifteen minutes' washing in running water should be ample, and the prints

may then be transferred one by one to the toning bath.

The most popular toning bath in this country is made as follows:

Distilled water	. .	16 oz. or 500 cc.
Ammonium sulphocyanide		30 grs. or 2 gms.
Gold chloride	. .	2 ,, or 0·13 ,,

This bath occasionally gives difficulty in toning, and if so should be tested with blue litmus paper. If the litmus paper turns red it will indicate that the bath is acid and a few drops of weak ammonia should be added until it becomes neutral. It may also give uneven toning through being exhausted; two to three ounces of solution are required for each 12×10 print.

Toning takes from two to five minutes according to the colour required. The prints are then given a few minutes' washing in running water, and are transferred to the fixing bath, made up of

Hypo	. . .	6 oz. or 150 gms.
Water	. . .	40 oz. or 1000 cc.

Ten minutes should be allowed for fixing and the prints are then given the final washing, which should be for at least one hour in running water. This last wash, the object of which is to remove all traces of hypo from the film, must be thoroughly carried out in order to ensure as long life as possible to the finished prints.

A combined toning and fixing bath recommended by Mr. H. W. Bennett, may be prepared as follows:

A.	Hypo	1 lb.
	Water, sufficient to make	32 oz.
B.	Ammonium sulphocyanide	2 oz.
	Water to make	8¼ oz.
C.	Lead acetate	1 oz.
	Water to make	8¼ oz.

The lead acetate should be dissolved in very hot water, as nearly boiling as possible. The solution will be cloudy, and should be shaken up before measuring out any quantity required.

D.	Gold chloride	15 grs.
	Water	3 oz.
E.	Ammonia (·880)	3 drs.
	Water	10 oz.

To prepare the toning bath, take 3 oz. of A and 3 drs. each of B C D and E and add sufficient water to make the total quantity up to 10 oz. This quantity of bath is sufficient for eight whole-plate prints, for fifteen half-plate, or for thirty-two quarter-plate prints.

It is very important that the solutions should be mixed in the order of the letters of the alphabet. The necessary quantity of A should be taken first, B added next, then C, and so on. After measuring C the measure must be

thoroughly rinsed before using it for D, and again thoroughly rinsed before measuring E.

Toning and fixing in this bath will take from twelve to fifteen minutes, and a very thorough final washing should be given.

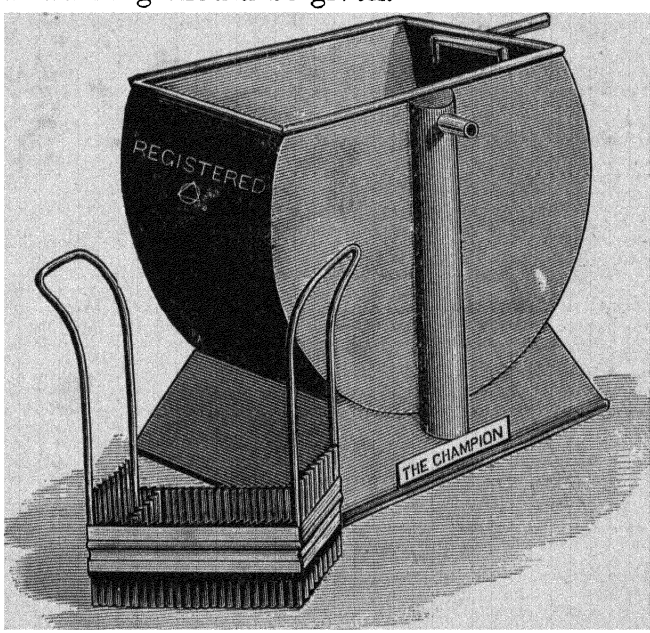


Fig. 48. Example of plate and print washer.
(Houghtons Ltd.)

An extremely simple and economical bath, much in vogue in the United States, is prepared by adding a grain of gold chloride to 20 oz. of distilled water and just rendering the solution alkaline by the careful addition of a few drops of a weak solution of sodium bicarbonate. Red litmus

paper will turn faintly blue when this condition has been reached.

For X-ray work it is very desirable that a brilliant glaze be imparted to the prints. This can be done by squeegeeing the washed prints on to perfectly clean glass or ferrotype plates. Prints so glazed are apt to stick to the glass or plates unless hardened in an alum bath first. A 5 per cent. solution of potash alum or 2 per cent. solution of chrome alum will suffice for this purpose, and the prints should be left in the hardening bath for ten minutes after the final washing and well rinsed before being glazed. Glass used for glazing should be thoroughly cleaned with water or water containing a little soda if greasy, and when dry should be polished with a clean rag and a little French chalk. Ferrotype plates are, on the whole, more satisfactory and can be obtained from any photographic dealer. Prints are squeegeed film downwards upon the plates, too much pressure not being used, and they should, if possible, be dried in a warm room or a few feet away from a stove. When perfectly dry one corner may be raised up by means of a penknife and the print pulled off the plate. An excellent stripping solution is supplied by the Gem Dry Plate Co., Ltd., Cricklewood, which ensures the prints leaving the glazing material.

P.O.P. prints prepared in this way give perhaps the finest results for radiographic diagnosis, but

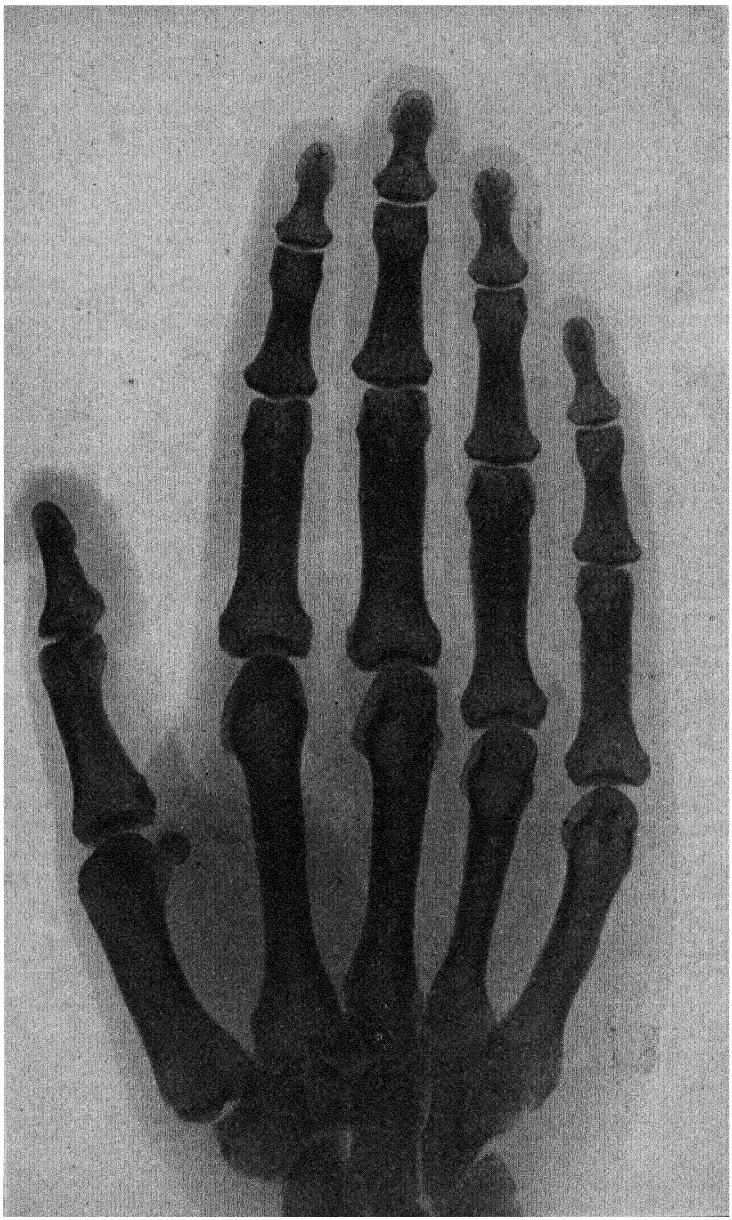


FIG. 49. Correctly printed radiograph of hand, showing evenly distributed contrast and density.

for ease of manipulation the gaslight process is certainly to be preferred.

Gaslight Papers.—These papers vary a good deal in speed and character, and are made by some makers in different grades which yield prints of varying degrees of hardness. Most gaslight papers possess the inherent quality of giving contrast, and are therefore specially suitable for negatives lacking contrast. By suitable exposure and development they will yield prints comparable in quality with P.O.P. or bromide paper.

X-ray negatives are usually on the dense side, and require fairly long exposure, hence a good light source is desirable for printing. Two incandescent gas burners placed closely together make a very suitable source of light, or a fifty or sixty Watt metal filament electric lamp. We recommend the former, as the light is better distributed, and as the size of the negative involved is more often than not 12×10 in. or over, it is important to ensure an equal distribution of light over the comparatively large area. The printing frame should not be more than 6 or 8 in. away from the light during exposure, and it is better to hold the printing frame in the hand and move it with a circular motion to equalise the illumination. Weak daylight is ideal for providing a diffused printing light, but it is often difficult to avoid over-exposure. Nothing less than

five or six seconds should be given for the best results.

If gaslight paper be worked in the ordinary dark-room light, some sort of screen should be employed behind which the frame is loaded and the development is carried out, in order to shield the paper from direct rays; otherwise the paper should only be handled several feet away from the light.

The necessary exposure is not always easy to gauge even by experienced operators, and it will often save waste if a test exposure be made with a narrow strip of paper, placed under a fairly representative part of the negative, and by covering say two-thirds of the paper by means of a piece of cardboard placed over the front of the printing frame, giving an exposure of 10 seconds, for example, then an exposure of a further 10 seconds with two-thirds of the paper exposed, and a further 10 seconds' exposure with the cardboard removed; in this way the three sections of the strip will have received 30, 20, and 10 seconds' exposure respectively, and on development it will be seen which part was most correctly exposed. With a dense negative, test exposures of perhaps one, two, and three minutes would be advisable; but everything depends on the speed of the paper, the power of the light source, and the distance between light and printing frame.

The exposure will be increased as the square of the distance between the light and the frame; thus if 20 seconds be the exposure with the frame 12 in. away, 80 seconds would be wanted with the frame 24 in. away, and so on, or if the exposure

at 6 in. were 1 second,
at $8\frac{1}{2}$ in. it would be 2 seconds,
at 12 in. it would be 4 seconds,
at 17 in. it would be 8 seconds, and
at 24 in. it would be 16 seconds,

and so on.

It may be mentioned that Messrs. Thos. Illingworth, Ltd., make a special series of gaslight papers for radiographic work, which yield good gradation with ample contrast, and are tolerably fast. Some idea of the advantage of gaslight over bromide paper for printing from weak negatives may be seen from a comparison of the prints shown in Figs. 50 and 51. The print shown in Fig. 51 was made on gaslight paper, Fig. 50 on bromide; the latter was the best result obtainable from a very bad negative, and is quite useless, while Fig. 51 is just sufficiently good for examination.

The chief essential in gaslight paper printing is *correct exposure*. Little can be done with an incorrectly exposed print. Development should be complete in from 30 seconds to a minute with most makes of paper, though it is safe to develop for longer with others. Prolonged development

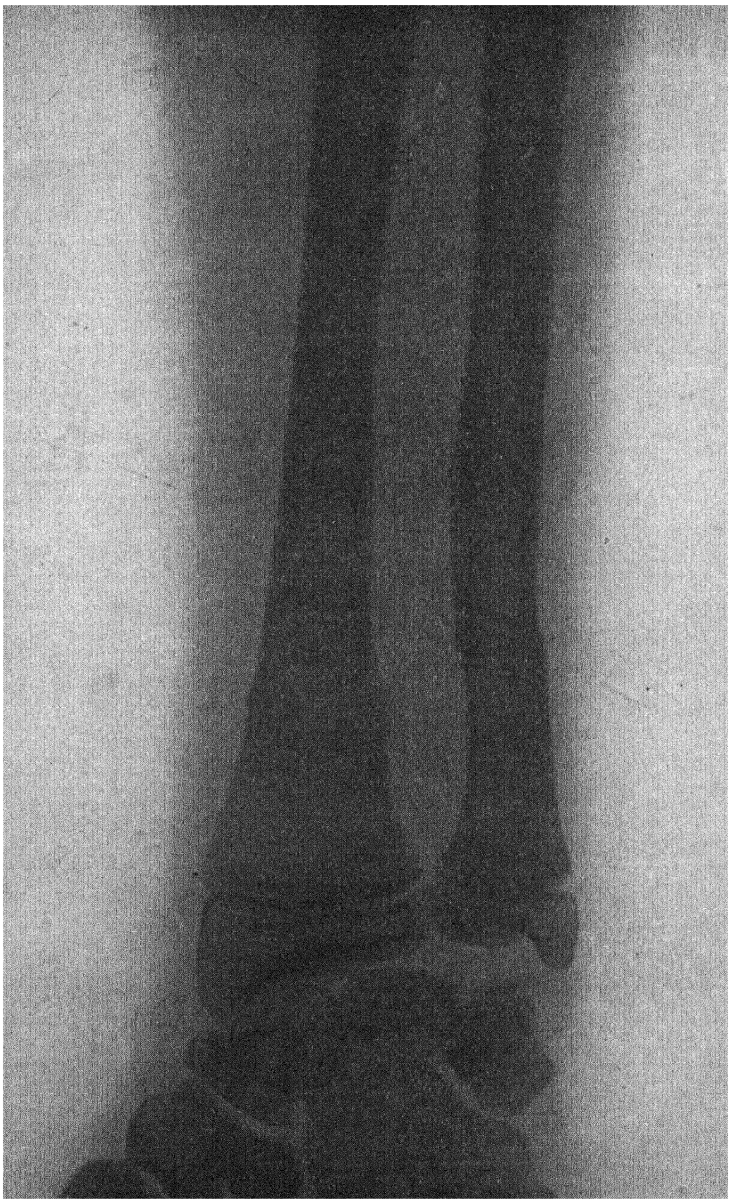


FIG. 50. Bromide print from negative of slight fracture.
(Unsuitable printing process.)

usually gives yellow stains in the 'whites' and ruins the print.

The original formula for use with Velox paper is as follows, and is an excellent developer:—

Metol	8 grs.	or	0·5 gms.
Hydroquinone . .	30 „	or	2 „
Sodium sulphite (cryst.)	¾ oz.	or	21 „
Sodium carbonate (cryst.)	¾ oz.	or	21 „
Potassium bromide .	2 grs.	or	0·13 „
Water	10 oz.	or	300 cc.

Another good developer, which must be freshly prepared, can be made with amidol, as follows:

Sodium sulphite (cryst.) . .	1 part.
Water	20 parts.

To 10 oz. of this solution (or 300 cc.) 50 grains of amidol (or 3·5 gms.) are added, and thoroughly dissolved, just before use; about 2 drops of 10 per cent. bromide solution should be added to each ounce or 30 cc. of developer. Too much bromide causes the prints to be greenish-black or brown in appearance. Over-exposed prints will flash up in development, the detail being lost; under-exposed prints will come up very slowly, and be extremely hard. It is waste of time to attempt to control development; if a wrong exposure has been given the only thing to do is to make a fresh print. Developer diluted with water will yield less vigorous prints, but for hard negatives it will be found better to use a make of gaslight

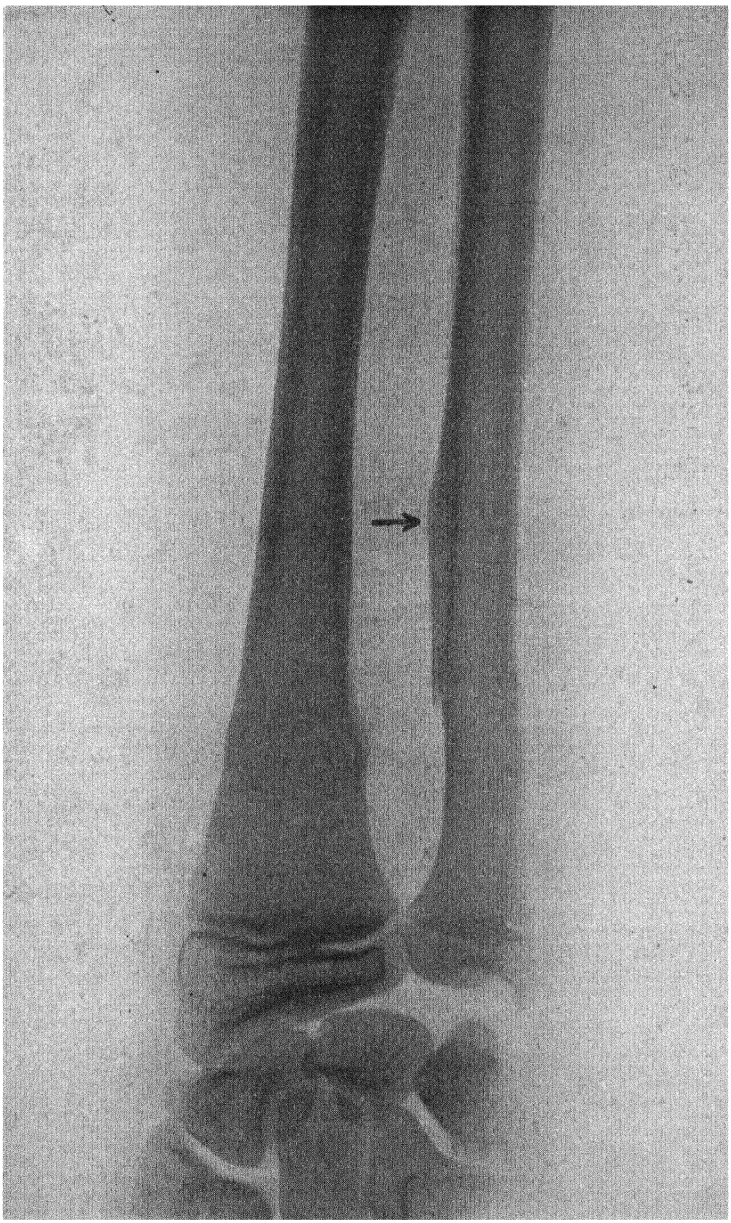


FIG. 51. Gaslight print from same negative, showing the fracture clearly.

paper specially manufactured for giving soft prints, or better still, bromide paper (*q.v.*).

An acid fixing bath should be used, a formula for such being given below:

Hypo	3½ oz.	or 100 gms.
Pot. metabisulphite .	½ ,,	or 15 ,,
Water	20 ,,	or 600 cc.

Eight to ten minutes should be allowed for fixing, and particular care should be taken, where several prints are fixed in one dish, to see that each one comes into perfect contact with the solution, otherwise yellow staining will result. Half an hour's washing in a print washer (Fig. 48) or with a print separately exposed to running water will suffice to cleanse them from traces of hypo. Prints made on glossy gaslight paper can be glazed in the way already described for P.O.P.

One trouble with both gaslight and bromide papers of the glossy variety may be mentioned here—this is the appearance of what are known as stress marks on the surface. These marks only appear on glossy papers, and can usually be removed by rubbing the wet prints with a piece of soft rag moistened with water or methylated spirit. In cases where stress marks are bad the following solution has been recommended:

Borax	1 part.
Methylated spirit . .	10 parts.
Water	40 ,,

FIG. 52. Ulcer on lesser curvature of stomach, and spasmodic hour-glass contraction. Taken with an intensifying screen. Half-second exposure.

Bromide Papers.—Bromide papers should be handled in plenty of bright yellow illumination, as it is impossible to judge properly the depth of a print in the light of a green or ruby safe-light. These papers are considerably faster than gaslight papers and require only a few seconds' exposure with a frame 6 to 18 in. away from the source of light.

In order to save waste of paper it will be often found worth while to make a test of the exposure with a small strip in the manner already described. It is also a good plan to choose one make of paper and keep to it; one then becomes thoroughly familiar with its characteristics and the loss of material is minimised. Metol-hydroquinone and amidol are the most popular developers, and the formulae already given will be found quite satisfactory, but should be diluted with half as much water again or even double the amount. The concentrated developer, however, will give prints containing the maximum contrast and may therefore be used when making prints from flat negatives.

There is considerably more latitude in the manipulation of bromide papers, as development may take from two to five minutes, and there is therefore some opportunity for coaxing an unexposed print. The print should never be taken out of the developing dish for examination.

When development is complete the print should

be fixed in the acid hypo bath already mentioned, and half an hour's final washing in running water should be afterwards given. A print washer for dealing with prints of all kinds will be found most useful, as a continual flow is given to the water in these devices which causes prints to turn over constantly, so that the films are all the time brought into contact with clean water.

Carbon Printing.—This is a process little used in radiographic work, yet strongly to be recommended where a permanent result is desired. It depends on the fact that gelatine treated with potassium dichromate becomes insoluble on exposure to light; gelatine with which a permanent pigment is incorporated, coated upon 'tissue,' *i.e.* a paper support, is sensitised by immersion in a solution of potassium dichromate, and when dry is exposed under the negative; it is then placed in water, and brought film to film with a previously wetted support paper, the two being after squeegeed together. On placing these in warm water, and peeling off the tissue, the pigment film adheres to the support, which is merely washed with warm water until the unexposed gelatine (the exposed gelatine is now *insoluble*) is washed away, leaving the pigment image behind. A little consideration will enable us to see that the image is reversed, so that the process as described is useful for negatives made with in-

tensifier screens exposed through the glass side of the plate.[1] If a 'temporary' support be used, the developed picture can be again transferred to a 'final' support when the reversal of the image is corrected.

Further description of this process cannot be given here, but full details of the working can be obtained from all treatises on photographic printing; an excellent guide to carbon printing, very briefly treated, is to be found in the *British Journal Photographic Almanac* for 1916. The materials are supplied by Thos. Illingworth, Ltd., and the Autotype Co. of Ealing.

Making Small Prints.—It is often a convenience to reduce negatives, either with the object of making lantern slides (or smaller negatives), or of making reduced prints, so that a number of prints from a series of negatives, as, for example, those taken of an opaque meal, can be mounted together in a handy way for reference. Dr. Robert Knox describes this method [2] in an article on 'The After Technique of the Opaque Meal,' where he reduces at one operation six 15×12 in. negatives arranged in a large viewing box to a $\frac{1}{1}$-plate or $\frac{1}{2}$-plate size.

A very simple reducing arrangement is used by Dr. Thurstan Holland, and is shown diagram-

[1] This method of exposure is not advocated, see p. 82.

[2] *Archives of Radiology and Electrotherapy*, April 1917.

matically in Fig. 53. A large box is arranged with an aperture AB to take the negative. Above and below the negative are placed electric lamps, the light of which is reflected from white cardboard, PQ, at the back of the lantern, thus illuminating the negative evenly. A camera of simple pattern is fixed to a horizontal support, and the whole apparatus is operated in the dark-room. The illuminated negative is then copied in the camera, a slow ordinary plate being used, or better still, a process plate. The best results

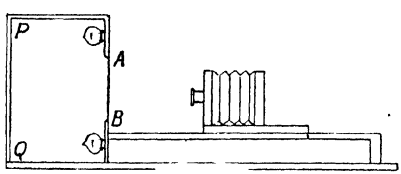


FIG. 53.

will be obtained by using a fairly small lens diaphragm F/16 or F/22, or smaller still if copying a weak or flat negative. The relative distance between negative, lens, and plate may be gathered from the following: If we are reducing, say, three linear times (from 12×10 in. to 4×3 in.), the lens being of 5 in. focal length, we multiply 3 by 5 and add 5, making 20 in. the distance between negative and lens. By dividing the focal length (in this case 5 in.) by the reduction (3) and adding the focal length to the result we get $\frac{5}{3}+5$ or $6\frac{2}{3}$ in. as the distance between lens and small plate.

The copy will, of course, be a positive, and a print made from it will be a negative comparable with the original negative. If a positive print be required, such as would be obtained by printing from the original negative, it will be necessary to make a transparency from the copy; this may be done with a process or lantern plate, making a contact exposure in a printing frame in the same way as a bromide print.

CHAPTER X

Industrial applications of the X-rays.

RADIOGRAPHY is gradually extending, in its applications, to industrial work, and is no longer confined to medicine. The advent of the Coolidge tube marked the opening of a new era in this respect, although prior to its introduction X-rays had been used in isolated instances such as for the destruction of larvae in high-grade tobacco leaf, and so on.

The work particularly referred to in this chapter is the use of very penetrating rays for the examination of wood, metals, and other substances, a new branch of scientific investigation which has sprung up with surprising suddenness, and one which may well open up a wide field for photographic operators who have specialised in radiography.

The control of the character of the rays, as generated by the Coolidge tube, is such that the delicate structure of the petals of flowers can be radiographed, with rays of extreme softness, while small defects such as blow-holes can be detected in the middle of pieces of hard steel two or more inches in thickness.

The examination of welding, the interior construction of apparatus, the condition of even such small apparatus as dry cells, the testing of large tanks and boilers, and so on, are all receiving consideration.

No one can say yet to what extent this work may be developed, but it may be mentioned that apparatus is being constructed with which it is anticipated that steel of 9 inches' thickness will be penetrated.

It will be realised that with apparatus capable of such work an entirely new field of radiography is opened up, which may well eventually eclipse medical work, which calls for considerable skill both in the manipulation of the X-ray apparatus and in the photographic treatment of the plates exposed. Small differences in density, *i.e.* weak contrasts, can by skilful treatment be intensified so as to reveal defects or flaws which would otherwise be practically lost. Pure photographic work will enter far more largely into radiomaterialography (as this work is called), than it does into medical work, and its success will depend to a large extent upon the degree to which advantage is taken of refined photographic treatment.

An early example of work done on metals with the rays was to photograph a piece of steel 2 in. in thickness, with a series of holes drilled in the upper surface, from $\frac{1}{64}$ in. in diameter to $\frac{1}{4}$ in. All these holes showed in the photograph, indi-

cating that a flaw $\frac{1}{64}$ in. in diameter could be detected in steel of this thickness. Pilon has examined welded iron and steel specimens and detected bad portions, and has photographed a fragment of steel from a saw in the centre of a piece of aluminium 8 cm. in thickness. Faulty welds in iron tanks, in gearcases of aircraft engines, and so on, have been detected—in fact, an almost endless field is opened up for work of this description. Wagner [1] has shown that it is quite possible to determine the position of blow-holes in the walls of steel ingots.

According to Pilon and Pearce, the thickness of metal which can be examined by radiometallography follows approximately the law of absorption modified by the emission of the secondary rays peculiar to each body. The absorption curve being logarithmic, the energy of the X-rays must clearly be largely increased in order to penetrate in the same time even small extra thicknesses of the same metal, and thus it is that in order to deal with any thickness of steel greater than 40 or 50 millimetres the apparatus necessarily acquires large dimensions. A potential of 100,000 to 250,000 volts is necessary, and Pilon recommends induction coils, using 6 milliampères at 150,000 volts with a 30 cm. equivalent spark-gap, or 4 milliampères at 120,000 volts. He also finds that when working with heavy currents hydrogen

[1] *Stahl und Eisen*, Dec. 21, 1916.

is a better dielectric than coal-gas for the mercury interrupter.

The probability is that induction coils will soon be superseded by high-tension transformers for this work, the transformer giving about 100,000 volts and the rotating rectifying disc being designed for a tension up to 180,000 volts. A transformer of 10 K.v.a. capacity is shown in Fig. 54; this has been designed for radiometallography by Watson and Sons (electro-medical), and has proved of considerable value.

The intensifying screen plays an important part in reducing exposure, cutting the time down to about one-fifteenth; by using a film in between two intensifying screens, Pilon found it possible to determine a difference in thickness of one-tenth of a millimetre (about $\frac{1}{250}$ in.) between two pieces of steel 45 millimetres in thickness. This fact is mentioned to show the high differentiating power of the X-rays, which have been in use in the United States also for testing the thickness of mica insulators for commutator construction.

A good deal of attention has been devoted to the subject of the intensifier screen for this work; it must give the absolute maximum of reduction in exposure, and must not give any sign of granularity in the negative image. It has been pointed out [1] that with hard rays a richer coating of calcium tungstate could be employed in an

[1] *Journal of the Röntgen Society*, No. 52, 1917.

intensifier screen than was effective with softer rays, and a screen has been prepared in which a

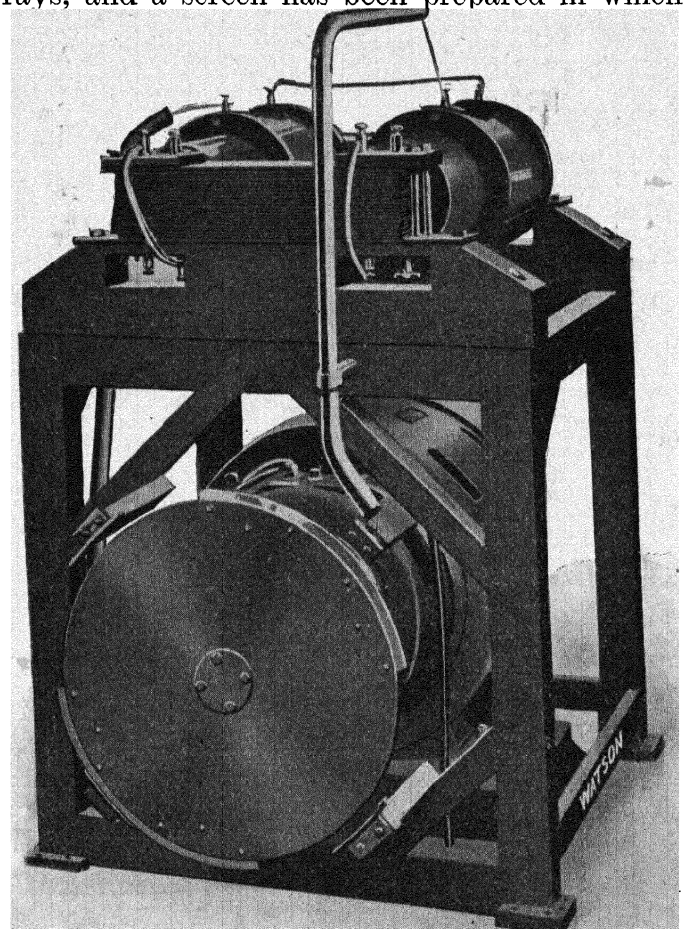


FIG. 54. High tension 10 K.v.a. transformer, with rotary rectifying disc mounted below.

heavy coating of the sensitive material has been used, which is made of excessively fine crystals so that irradiation is reduced to a minimum. Selected

crystals are also employed in order to obtain the greatest possible intensification. Such screens are more ' tender ' than those used for medical work, and care must be taken not to scratch or dent the surface. Both screen and plate should, therefore, be carefully dusted with a camel-hair brush each time the cassette is loaded. As with such a heavy discharge there is a tendency for the screen to phosphoresce after the exposure is concluded, if the plate is not to be immediately developed, it should be removed from the cassette and placed in a box in the lead-lined plate storage box until it is required for development. Where continuous work is to be carried on, it will be an advantage to have two or three screens so that each one is given a short rest before it is used again. It is also of advantage to use backed plates (see Appendix D).

The choice of plate has to be considered; with some makes of plate, it has been found that in conjunction with the intensifier screen an extremely rapid plate of the ordinary variety gives the quickest results; in other cases, certain makes of X-ray plates appear to admit of shorter exposures than extreme speed ordinary plates. Good results have been obtained by the author with Imperial flashlight plates. But there appears to be a certain amount of scope here for testing the plates with individual equipments, and deciding for oneself which brand is the best to employ.

The object to be photographed is surrounded by a lead diaphragm five or more millimetres in thickness, so that no direct rays can fall on the plate. In the case of an irregular object, it can be embedded in wax, and the wax trimmed off, so that it can be placed in a lead diaphragm and the upper peripheral irregularities filled in with lead shot; the wax prevents the shot from getting underneath, but a surface diaphragm is formed.

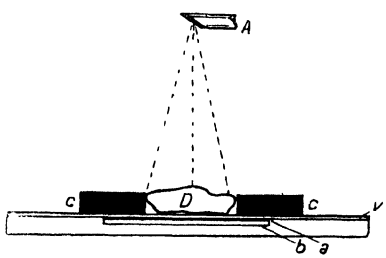


FIG. 55. Radiography of a metallic or mineral specimen of irregular shape.

The photographic plate is placed on a sheet of lead to protect it from any secondary radiation on the reverse surface. The exposure is then made, and the plate developed.

The protection of the operator is a matter which in this work needs the most careful consideration. X-rays which will penetrate two or three inches of steel are difficult to arrest, and it has been found that rays which will fog a photographic plate are sometimes emitted from the back of a tube. At least 5 millimetres of lead should be

used to line the tube box, the upper part of which (if the plate is exposed *above* it) should be covered with a heavy lead diaphragm with an aperture of the minimum requisite size. In the case of tubes run from 5, 10, or more K.v.a. transformers, far greater thickness of lead should be employed; in

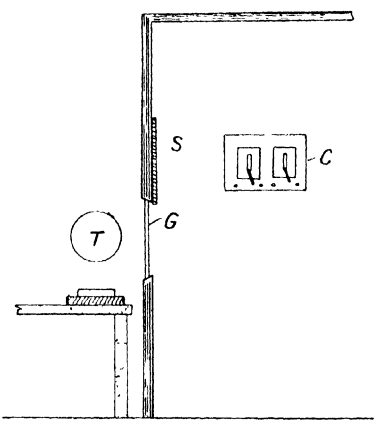


FIG. 56. Arrangement of operator's cubicle, with tube T outside, and lead glass window G.

fact, the weight of lead to protect against outside radiation may then run into a ton or more.

Those dealing with radio-metallography are earnestly advised to pay the most scrupulous attention to this subject, and to adopt some such method as that devised by Pilon, who provides a lead-lined cabinet for the operator, containing the controlling switch, exposure switch, and so on, and is provided with a lead glass window through which the tube can be examined to see

that it is functioning properly; a lead shutter can be drawn over the window during the actual exposure.

Little can be said regarding the nature of the exposures themselves; aeroplane timber, etc. can, of course, be examined with the fluorescent screen,

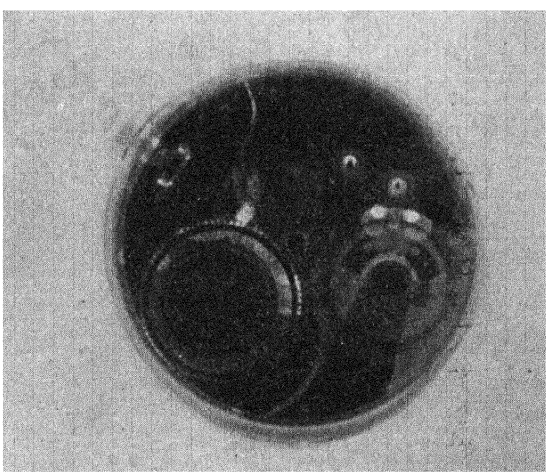


Fig. 57. (A) (See p. 168).

as can motor tyres, samples of vulcanisation, and so on; but photographic work depends on the nature of the metal or sample, the thickness, the power of the rays at one's command, and the quality of the intensifying screen. The Imperial Dry Plate Co., Ltd., make a special screen for this work, coated with exceedingly fine crystals of calcium tungstate tightly compressed, which reduces exposure to minimum and gives an image

remarkably free from grain. A richly coated X-ray plate, used in conjunction with this, will admit of exposures such as one to three minutes with specimens of steel two or three centimetres in thickness, with a 20 in. coil, or equivalent transformer.

A developing formula which is worthy of mention for this work, containing no bromide and giving maximum detail for any given exposure, is as follows:

Water (distilled) . . .	50 parts.
Metol	1 part.
When dissolved, add	
Sodium sulphite (cryst.) . .	6 parts.
Sodium carbonate (cryst.) . .	8 parts.

This developer should be made up freshly for each batch of plates, and used at 65 degrees F., not above. Three to four minutes' development should be given, and if any trace of fog appear in the plate, two or three drops of 10 per cent. bromide solution should be added to each ounce of developer.

In developing metallographic negatives it must be borne in mind that we are apt to get excessive density in certain parts, and the faintest detail in others, and that printing will be very difficult if these contrasts are too extreme. Subjects such as timber or wood specimens may give quite faint

contrasts, when intensification may prove of value, or at any rate careful printing with a vigorous make of gaslight paper. Where the density of the most exposed parts is excessive, over-exposure with bromide paper may be given, with a weak developer, or the negative may be selectively reduced by the method given on page 134.

As already stated, this work offers great scope for skilful photographic technique, and by careful

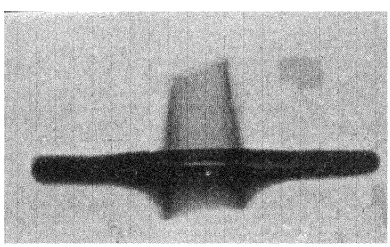


FIG. 59. (C) Faulty weld.

selection of a printing process and its manipulation crude results can frequently be very much improved.

It is hardly necessary to add that great care must be exercised in keeping packets of unexposed plates well protected from the rays, as they may easily become fogged.

. . . . .

The illustrations given in this chapter are from negatives kindly lent by Messrs. Watson and Sons, Ltd., and show (A) the contents of a watch, taken through the metal case; (B) six different makes

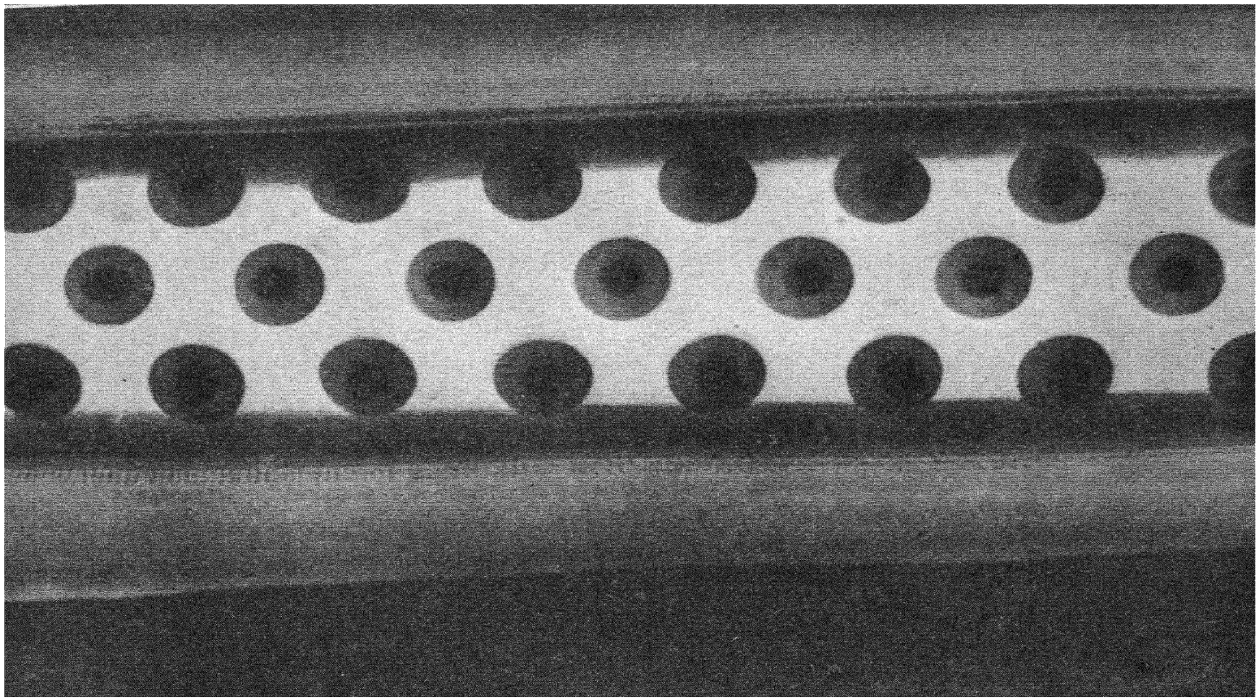


FIG. 60. (D) Showing construction of studded motor tyre.

of golf ball, showing clearly the variations in construction; (C) a flaw in a welded metal part, indicated by the white line between the two horizontal flanges, and (D), the structure of a studded motor tyre. These photographs were taken with a Watson 10 K.v.a. transformer and Coolidge tube, using Sunic X-ray plates, and give some idea of the diversity of applications possible.

CHAPTER XI

Analysis with the X-rays.

WHILE the rays given by an ordinary X-ray tube consist of a mixture of hard and soft rays of various wave-lengths, every substance can be made to emit homogeneous and characteristic X-rays, as was pointed out by Barkla, if stimulated sufficiently with the mixed rays. The wave-length of the characteristic X-rays given from different elements changes from element to element, according to their atomic number.[1]

When a beam of X-rays strikes a crystal, the regularly arranged structural units act like a diffraction grating, and the beam is reflected from the crystal, the angle of reflection differing for X-rays of different wave-length: hence we get an X-ray spectrum somewhat analogous to the spectrum of visible colours produced by

[1] The atomic number of an element defines the place-number or position occupied by the element in the periodic table, and, at the same time, is a measure of the number of electrons in the atom or the number of positive charges in the nucleus of the atom. Moseley showed, from a spectroscopic examination of the characteristic X-rays emitted by the various elements, that the square roots of the frequencies of corresponding lines are proportional to the atomic numbers.—*Journal Röntgen Society*, Jan. 1920.

reflecting white light from a metallic diffraction grating.

If a narrow pencil of X-rays be transmitted through a crystal and be then allowed to act on a photographic plate, the negative shows a series of symmetrically arranged dark spots—as shown by Lane—and different types of crystals give different patterns. A method of analysis based upon this fact has been worked out by Debye and Scherrer for both crystalline and amorphous substances and both organic and inorganic colloids. A. W. Hull has extended it to amorphous substances [1] by passing a beam of X-rays through absorbing screens, and producing a homogeneous beam thereby which passes through two slits (*q.v.*) and falls upon a cylindrical tube containing the powder to be analysed. The X-rays which are reflected from the particles in the tube affect a photographic film placed round it, and analyses may be made by comparing the result with those previously obtained with known elements or substances.

By means of an ionisation chamber, W. H. and W. L. Bragg obtained X-ray spectra, by passing a beam of X-rays through two slits placed a little distance apart, so that a fairly parallel beam fell upon the cleavage plane of a crystal; what would be the telescope in a spectrometer was the ionisation chamber, and the reflected X-rays were

[1] *Journal American Chemical Society*, Aug. 1919.

measured by the ionisation effect as evidenced by an electroscope. According to Kaye,[1] both the incident and the reflected radiations consist essentially of the same constituents, but the different constituents of the incident beam are not reflected equally by the crystal, with the result that the two differ in their average hardness. Owen and Blake by using narrow pencils of rays, obtained by photographic means spectra of well-defined lines, by measuring the positions of which X-ray spectrographic analysis became possible.

As an example of the practical application of X-ray analysis the work of Moseley[2] may be quoted, in which he produced a series of X-ray spectra by using a different metal for the anticathode in each case, this generating a very high proportion of characteristic rays, as pointed out by Kaye, if the tube is used in a soft condition. The more intense line in each spectrum, due to the K characteristic radiation, reveals the fact that both copper and zinc are present in brass, both lines appearing when a brass anticathode was used; similarly cobalt showed the presence (as impurities) of both iron and nickel. A crystal of potassium ferrocyanide was used as the dispersing medium.

Professor J. W. Nicholson[3] has described to

[1] *X-Rays*, p. 188. [2] *Phil. Mag.*, Dec. 1913.
[3] *Journal Röntgen Society*, Jan. 1918.

the Röntgen Society some of the work done by M. de Broglie on the absorption spectra of X-rays. The rays are split up into a spectrum in the way above described, and a spectrum of the radiation is obtained, giving the sequence of effects produced by the various wave-lengths. If the absorption of the rays by a body be measured for various wave-lengths, *i.e.* rays of different hardness, there are found two particular regions of maximum absorption, one fairly sharply defined, the other more banded. The first is due to K radiation, the second to L radiation. The photographic plate being prepared with a salt of silver, an impression is produced on the plate in the position corresponding to the K radiation of silver; (a very slight impression due to bromine [v. p. 28], is formed also). The impression is a band or patch which stops sharply on the side corresponding to the greatest wave-length, and gradually on the other side. If some element capable of absorbing characteristic rays be placed in the path of the radiation producing the band, a radiation being used which contains the characteristic radiation for that element, its absorption is shown near the K and L bands in the photographic spectrum. Over the black portion of the negative due to the silver radiation can be superposed the effect of the interposed element, which through its absorption shows a light patch. If the atomic weight of the element be less than

that of silver, its K radiation has the longer wavelength, and the dark patch due to silver is obliterated. If the atomic weight of the element be greater than that of silver, we get a light patch due to the stoppage of its characteristic radiation superposed on the silver patch.

The reader is referred to the *Journal of the Röntgen Society* for a fuller explanation of this work. It is beyond the scope of this book to do more than refer to the subject, but some account has been given as there is little doubt that analysis by means of X-spectra and absorption spectra will ere long form yet another branch of the photographic side of radiographic work.

APPENDIX

A. PLATEMAKERS' DEVELOPMENT FORMULAE, ETC.

IMPERIAL DRY PLATE CO., LTD., X-RAY PLATE.

No. 1 Solution

Potassium metabisulphite .	½ oz. or	12 grs.
Hydroquinone . . .	½ ,, or	12 ,,
Potassium bromide . .	½ ,, or	12 ,,
Water	20 ,, or	500 cc.

No. 2 Solution

Caustic potash . . .	1 oz. or	25 gms.
Water	20 ,, or	500 cc.

Use equal parts of No. 1 and No. 2, and develop for three to five minutes. Rinse well, and fix in

Water	20 oz. or	500 cc.
Potassium metabisulphite .	1 ,, or	25 gms.
Sodium hyposulphite . .	6 ,, or	150 ,,

WELLINGTON PLATE.

Metol-hydroquinone

Metol	20 grs.
Hydroquinone	80 ,,
Sodium sulphite (cryst.) . .	1000 ,,
Sodium carbonate (cryst.) . .	1000 ,,
Potassium bromide . . .	10 ,,
Water to	20 oz.

Dissolve in the order named.

Hydroquinone

(*A*). Hydroquinone	1 oz.
Sodium sulphite (cryst.)	8 oz.
Potassium bromide	120 grs.
Water to	80 oz.
(*B*) Caustic soda (pure)	1 oz.
Water to	80 ,,

When making up the *A* solution in this developer, the sodium sulphite should be dissolved in the water before adding the hydroquinone.

After development the plate should be rinsed for at least thirty seconds before placing in the following

Fixing Bath

Hypo	1 lb.
Potassium metabisulphite	½ oz.
Water to	80 ,,

Wash as usual.

Ilford, Ltd.

Metol	1 gm.	or 20 grs.
Hydroquinone	4 gms.	or 80 ,,
Sodium sulphite (cryst.)	50 ,,	or 2 oz.
Sodium carbonate (cryst.)	50 ,,	or 2 ,,
10% bromide solution	4 cc.	or 80 mins.
Water	500 cc.	or 20 oz.

Dissolve the metol and hydroquinone first in warm water, then add the sulphite and other ingredients in the order given. For use, dilute with an equal volume of water.

Pyro-potash developer, No. 1

Pyrogallic acid	30 gms.	or 1 oz.
Potassium metabisulphite	7·5 ,,	or ¼ ,,
Water, to make	900 cc.	or 30 ,,

No. 2

Potassium carbonate (anhydrous)	90 gms.	or 3 oz.
Sodium sulphite (cryst.)	90 ,,	or 3 ,,
Potassium bromide	2 ,,	or 30 grs.
Water, to make	900 cc.	or 30 oz.

For use, mix equal quantities of No. 1 and No. 2.

Stand Developer. Stock Solution

Water	480 cc.	or 24 oz.
Sodium sulphite (cryst.)	50 gms.	or 2½ ,,
Dissolve, and add		
Glycin	20 ,,	or 1 ,,
Potassium carbonate (anhydrous)	100 ,,	or 5 ,,

Add the potassium carbonate gradually, as some effervescence occurs. For use, add one part of the above solution to ten parts of water.

SUNIC PLATE.

Sutol-hydroquinone. Single Solution

Sutol	50 grs.	or 2 gms.
Hydroquinone	½ oz.	or 10 ,,
Sodium sulphite	2 ,,	or 40 ,,
Sodium carbonate	2 ,,	or 40 ,,
Potassium bromide	10 grs.	or 0·4 ,,
Water	50 oz.	or 1000 cc.

BARNET X-RAY PLATE.

Metol-hydroquinone. Single Solution

Metol	30 grs.	or 2 gms.
Hydroquinone	120 ,,	or 8 ,,
Sodium sulphite	3 oz.	or 100 ,,
Sodium carbonate	3 ,,	or 100 ,,
Potassium bromide (10% solution)	120 mins.	or 8 cc.
Water (boiled or distilled)	30 oz.	or 1000 cc.

Fixing Solution

Sodium thiosulphate . .	1 lb.	or 400 gms.
Potassium metabisulphite .	1 oz.	or 25 ,,
Water	40 ,,	or 1000 cc.

B. BRITISH MEASURES

Apothecaries' weight, by which formulae are made up.

20 grains = 1 scruple.
3 scruples = 1 drachm.
8 drachms = 1 ounce (= 480 grains).

Avoirdupois weight, by which chemicals are sold.

437·5 grains = 1 ounce.
16 ounces = 1 pound.

Fluid measure.

60 minims = 1 drachm.
8 drachms = 1 ounce (= 480 minims).
20 ounces = 1 pint.
40 ounces = 1 quart.
4 quarts = 1 gallon.

Metric measures are approximately equivalent, as follows, to English measures :

1 gram = 15·4 grains.
28·4 grams = 1 ounce.
454 grams = 1 lb.
1 kilogram (1000 grams) = 2·2 lbs.
1 cubic centimetre (cc.) = 17 minims.
100 cc. = 3½ ounces.
1000 cc. or 1 litre = 35 ounces.
4540 cc. = 1 gallon.

N.B.—An average 'Winchester Quart' bottle holds 80 ounces, or about 2200-2300 cc.

C. TABLE OF CHEMICAL FORMULAE,

giving molecular weights

Acid, acetic	$C_2H_4O_2(CH_3.COOH)$	60
,, hydrochloric	HCl	36·5
,, nitric	HNO_3	63
,, pyrogallic	$C_6H_3(OH)_3$	126
,, sulphuric	H_2SO_4	98
Alcohol (ethyl)	$C_2H_5.OH$	46
Alum, chrome	$K_2Cr_2(SO_4)_4.24H_2O$	998
,, potash	$Al_2K_2(SO_4)_4.24H_2O$	948
Amidol	$C_6H_3.OH(NH_2)_2.2HCl$	197
Ammonia	NH_4OH	35
Ammonium chloride	NH_4Cl	53·5
,, sulphocyanide	NH_4CNS	76
Barium sulphate	$BaSO_4$	233
,, platinocyanide	$BaPt(CN)_4.4H_2O$	508
Calcium chloride, anhydrous	$CaCl_2$	111
Eikonogen	$C_{10}H_5(OH)NH_2SO_2.ONa$	263
Formaline	$H.COH$	30
Glycerine	$C_3H_5(OH)_3$	92
Gold chloride (yellow)	$AuCl_3.HCl.4H_2O$	412
Hydroquinone	$C_6H_4(OH)_2$	110
Iron perchloride	$FeCl_3$	162·5
Iron oxalate (ferrous)	$FeC_2O_4.2H_2O$	180
Lead acetate	$Pb(C_2H_3O_2)_2.3H_2O$	379
Mercuric chloride	$HgCl_2$	271
,, iodide	HgI_2	454
Metol	$(C_6H_4OH.NHCH_3\rho)_2.H_2SO_4$	344

Ortol	$C_6H_4OH(NHCH_3p)+$ $C_6H_4(OH)_2p$	234
Paramidophenol	$C_6H_4NH_2.OH$	109
Potassium bichromate	$K_2Cr_2O_7$	294
,, bromide	KBr	119
,, carbonate	K_2CO_3	138
,, hydroxide	KOH	56
,, chloro-platinite	K_2PtCl_4	415
,, ferricyanide	$K_3Fe(CN)_6$	329
,, ferrocyanide	$K_4Fe(CN)_6.3H_2O$	422
,, oxalate	$K_2C_2O_4.H_2O$	184
,, persulphate	KSO_4	135
Pyrocatechin	$C_6H_4(OH)_2$	110
Silver bromide	AgBr	188
,, chloride	AgCl	143·5
,, iodide	AgI	235
,, nitrate	$AgNO_3$	170
Sodium bicarbonate	$NaHCO_3$	84
,, bisulphite	$NaHSO_3$	104
,, carbonate (anhydrous)	Na_2CO_3	106
,, carbonate (crystals)	$Na_2CO_3.10H_2O$	286
,, sulphate ,,	$Na_2SO_4.10H_2O$	322
,, sulphite (anhydrous)	Na_2SO_3	126
,, sulphite (crystals)	$Na_2SO_3.7H_2O$	252
,, thiosulphate ('hypo')	$Na_2S_2O_3.5H_2O$	248
Uranium nitrate	$UO_2(NO_3)_2.6H_2O$	502·5

D. USEFUL FORMULAE

Backing for Dry Plates.—It is sometimes an advantage, especially in radiometallographic work, when using an intensifying screen, to back the plates, *i.e.* coat the glass side with a light absorbing medium to prevent the screen image from becoming diffused by reflexion from the back of the plate. A medium which can be applied

to the glass side of the plates with a stiff brush may be prepared as follows :

Ordinary liquid gum . .	4 oz.	or 100 cc.
Caramel	4 ,,	or 100 ,,
Burnt sienna, ground in the least possible quantity of water	8 ,,	or 200 ,,
Mix up in a mortar, and add		
Methylated spirit . .	2 oz.	or 100 cc.

Dead Black Varnish-stain for Wood.

Water	8 oz.	or 250 cc.
Borax	30 grs.	or 2 gms.
Shellac (white) . . .	60 ,,	or 4 ,,
Glycerine	30 mins.	or 2 cc.
Boil until dissolved, and add		
Nigrosine (soluble in water)	60 grs.	or 4 gms.

Dextrine Paste for Mounting Prints.

White dextrine . . .	11 oz.	or 300 gms.
Water	20 ,,	or 500 cc.

Add the dextrine slowly, with stirring, to the water at a temperature of 160 degrees F. When all is dissolved, add

Oil of wintergreen	4 drops.
Oil of cloves	4 ,,

Pour into wide-mouthed bottles, when in a few days the mountant will congeal and form a smooth white paste.

E. STEREOSCOPIC RADIOGRAPHY [1]

Thickness of part to be radiographed.	Distance from anticathode to surface of body.			
	20 cm.	30 cm.	40 cm.	50 cm.
	Tube Displacement. (Centimetres.)			
Centimetres.				
2	4·4	9·6	16·2	
4	2·4	5·4	8·8	13·5
6	1·7	3·6	6·1	9·3
8	1·4	2 8	4·1	7·3
10	1·2	2·4	4	6
15		1·8	2·9	4·3
20		1 5	2·4	3·5
25		1·3	2·1	3
30		1·2	1·9	2·7

F. SPARKING POTENTIALS [2]

Spark-Gap.		Between balls of 0·5 cm. diameter (D.C.)	Between needle-points (A.C.)
Cms.	Inches.		
·1	·04	5,000	1,000
·5	·20	16,000	6,000
1	·39	21,000	12,000
2	·79	24,000	24,000
3	1·18	26,000	34,000
4	1·58	27,000	42.000
5	1·97	Brush	49,000
7	2·76	discharge	61,000
10	3 54	usually	76,000
15	5·91	occurs	102,000
20	7 9		122,000
30	11·8		170,000
40	15·8		220,000

[1] Marie and Ribaut.

[2] From Kaye's *X-Rays.*

G. THE COOLIDGE TUBE

An endeavour has been made in this book to deal chiefly with matters relating to the photographic side of X-ray work, and to omit those which are dealt with in so many other treatises on general radiology. The Coolidge tube, however, is of such importance that some description of it can hardly be omitted, and by the courtesy of Messrs. Newton and Wright, Ltd., their following clear and simple description of the tube is given below.

'The Coolidge tube undoubtedly marks an epoch in X-ray technique.' All X-ray tubes previously made contained a residue of air or other gas, and the electrified molecules of this gas have formed the medium by which the current has been enabled to pass through the tube, the "hardness" or otherwise of the tube depending largely upon the amount of such gas left in it from the pump, or introduced later by some regulating device. In the Coolidge tube the exhaustion is carried to a much higher point until a practically perfect vacuum is obtained, and in this condition the tube becomes so "hard" that under normal conditions no current can be passed through it.

'The principle, however, which Dr. Coolidge applied in the construction of his tube, depends upon the fact, previously known to science, that if the negative electrode in such a vacuum is made sufficiently hot, it will emit electrons which will perform the same function as the rarefied gas.

'In the Coolidge tube this result is obtained by making the cathode or negative electrode in the form of a spiral of tungsten wire, which can be heated by means of an independent low-tension electric current, either obtained from a storage battery or from a transformer or other suitable means.

'The spiral of tungsten wire is mounted in a cup or tube of molybdenum, which serves the double purpose of concentrating or "focussing" the electrons, and also preventing any electron discharge from taking place from the back of the spiral. The current required for heating the tungsten varies between 3·5 and 5 ampères at an E.M.F. of approximately 12 volts, and may be either continuous or alternating; it can therefore be supplied from a small accumulator, a step-down transformer working from the A.C. mains (or in connection with a rotary converter if the mains are D.C.), or, in fact, from any arrangement which will provide the necessary supply. As, however, the entire circuit has to be raised to a potential of many thousands of volts (being in connection with the cathode of the tube) corresponding insulation has to be provided.

'If an accumulator is used as the source of supply, the entire battery is generally mounted upon an insulated stand together with ammeter and regulating resistance, the control handle of the latter being also well insulated, in order that it may be operated when in use.

'A step-down transformer, with or without a rotary converter, according as the mains are A.C. or D.C., has, however, very obvious advantages over an accumulator which needs constant charging attention, and is now therefore but seldom used.

'In the case of these transformers, the insulation required is usually provided between the primary and secondary windings; the control can therefore be exercised on the primary side, which is, of course, low tension only.

'The Coolidge tube is much more expensive than other tubes (now frequently termed "gas" tubes), and the necessity for heating the cathode is an additional complication that must be regarded as a drawback, but, on the other hand, it has great advantages, the principal ones being its relatively long life, the readiness with which

both the penetration and the amount of current passing can be regulated, and not only regulated, but maintained without any variation.

'As previously stated, the Coolidge tube in its normal condition is so highly exhausted that no current can be passed through it, and the cathode or negative electrode must be brought to a high temperature before it can be used.

'As the amount of current that can be passed depends

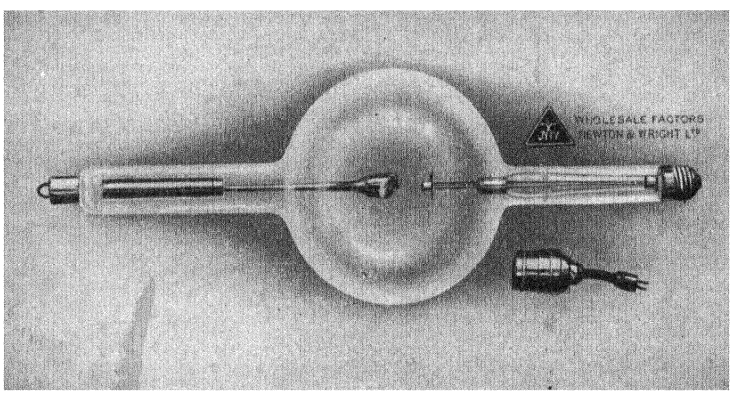


FIG. 61. Ordinary type of Coolidge tube. The screw-on cap shown leads to the low voltage secondary of the transformer for heating the cathode spiral.

upon the temperature of the cathode, and this again depends upon the amount of current used in the local or filament circuit, means for regulating this must be provided, and must allow of very delicate control.

'The minimum temperature for the cathodes at which the tube will work may be taken as approximately 1700 degrees centigrade, and the maximum required, or safe in practice, as 2350 degrees centigrade.

'Let us suppose the tube to be duly connected up to the terminals of a high-tension transformer or induction

coil having an alternative spark-gap set at say 5 inches, the filament circuit also being connected to the accumulator or step-down transformer but nothing switched on.

'The first step should be to switch on the heating circuit, the current being at its minimum, and gradually increase this until the cathode is just white hot, passing say 4 ampères. The coil or transformer should then be switched on with a weak current when the needle of the milliampèremeter will indicate some reading, or alternatively sparks will pass across the spark-gap. The latter will, in this case, be acting as a safety valve, and will guard against the danger of puncturing the tube.

'Without testing with a screen, the reading of the milliampèremeter is the only indication that current is passing, as the Coolidge tube does not exhibit the familiar green glow characteristic of other tubes. If no current passes through the tube, the filament current should then be gradually increased until sparks just do not pass across the spark-gap.

'If the cathode is at its minimum temperature or thereabouts, the resistance of the tube will be high, and the current passing will be small.

'It may here be noted that the Coolidge tube differs from other tubes in this, that for any given temperature of the cathode, the current it will pass is strictly limited, and no amount of additional output from the coil will increase it, the fact being that the quantity of electrons, liberated at a definite temperature, will carry a certain number of milliampères and *no more* (the tube then being "saturated") until the temperature is raised.

'If *more* current is required, therefore, the temperature of the cathode must be increased, when the resistance of the tube will be lowered, and the current passing will correspondingly increase provided, of course, that the output from the coil or transformer is sufficient to allow it to do so.

'The *penetration* of the tube, on the other hand, depends, not upon "hardness," in the sense that this term is generally used, but upon the tension or voltage applied to its electrodes, and this is most easily measured by means of the alternative spark-gap.

'If this is set, say, at 5 inches, as above stated, and the apparatus adjusted until the discharge just does not pass across it, we obviously have a certain definite E.M.F. at the electrodes, and this represents an equally definite quality of penetration in the rays. To reproduce this degree of penetration another time it is only necessary to set the spark-gap to the same distance and adjust the current till again it is barely sufficient to jump across it, and if at the same time by varying the heat of the cathode we obtain also the same milliampèrage, we know that the conditions we had previously are exactly reproduced.

'Thus, supposing a tube to be "saturated" or passing as much current as it will pass at that particular cathode temperature, cutting out primary resistance in the generating coil or transformer, and thereby increasing its voltage or spark length discharge, does not pass more current through the tube (which is already passing as much as it can at that particular temperature) but *does* increase its penetration. Heating the cathode still further immediately allows more current to pass, and this, as a rule, results in lowering the E.M.F. at the terminals, and thereby reducing the penetration.

'Increasing further the E.M.F. of the coil or transformer, the penetration is again restored, but the current is not further increased until the temperature is once more raised, and this process can be repeated indefinitely until either the limit of available current is reached, or the tube is carrying as much as it can with safety.

'The maximum amount of current that the tube will carry safely depends upon several factors, one of the most important being the fineness or otherwise of the

focus. The ordinary pattern Coolidge tube is made in three varieties in this respect, viz., those with fine, medium, or broad focus, and will carry for a short time for radiographic purposes, 25, 50, or 80 milliampères respectively, at an equivalent spark-gap resistance of 6 inches. With a harder tube, or for longer exposures, the current must be reduced below this, or for "Flash" work it may be increased.

'The limiting factor in these cases is the melting point of the focal spot on the tungsten target, which will be

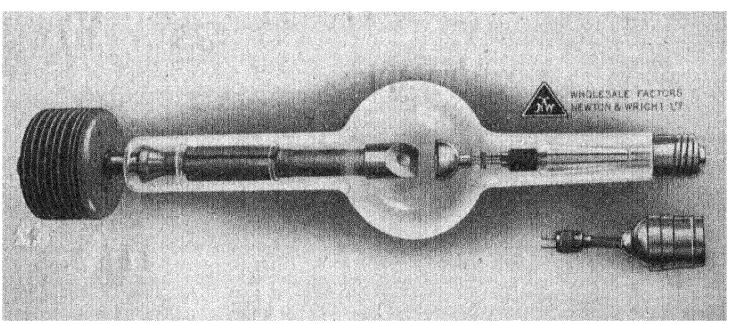


FIG. 62. Coolidge tube with small bulb and metal disc radiator for cooling anode.

reached if the above figures are exceeded, but for therapeutic work the limit is generally the glass of the bulb, which, with prolonged use, may even be melted.

'While dealing with this question of heat it may be mentioned that as the current is carried across the tube by means of electrons, liberated by the hot cathode, inverse current *cannot pass* until the target (which for inverse current is, of course, the cathode) becomes hot enough to emit electrons in its turn, and therefore for moderate currents the tube is self-rectifying. If some special means be taken to keep the target cool, such, for example, as in the "Radiator" type (Fig. 62), the tube

is absolutely self-rectifying for all moderate currents, and may even be used direct on a high-tension alternating current transformer without any rectifier or valve of any sort.'

H. RECOMMENDATIONS OF THE RÖNTGEN SOCIETY (1915) FOR THE PROTECTION OF X-RAY OPERATORS

The harmful effects produced by X-rays are cumulative and do not generally appear until some weeks or months after the damage has been done. It is to be noted that X-rays of any degree of hardness are capable of producing ill effects, although it is commonly supposed that soft rays only are harmful.

It is undesirable that any X-ray treatment should be carried out except under the direction of a qualified medical practitioner experienced in X-ray work.

All X-ray tubes must be provided, when in use, with a protecting shield or cover which prevents the access of rays to the operators and which encloses the tube, leaving an adjustable opening only sufficiently large to allow the passage of a sheaf of rays of the size necessary for the work in hand. Even with this shielding the operator may not be completely protected in all cases (*e.g.* especially in screen work), and the use of movable screens, gloves, and aprons is recommended.

Operators should be warned that shields obtainable commercially are often ineffective, and tests of their opacity should be made.

Whenever possible the cubicle system should be used for X-ray treatment, and the operator should be able to make all adjustments from a protected space.

When screen examination is required it is essential that the screen should be covered with thick lead glass of proved opacity and that the screen should be inde-

pendently supported and not held in the hands of the operator. If the hands are so used they should be properly protected.

The hand, or any portion of the body of the operator should never be used to test the hardness or quality of the X-ray tube ; any simple form of penetrometer can be easily arranged for this purpose.

I. CAUTIONS REFERRING TO THE DANGERS OF SHOCK, ETC., FROM THE HIGH-TENSION CURRENT OF X-RAY INSTALLATIONS

(By courtesy of Messrs. Watson and Sons (Electro-Medical), Ltd.)

1. All metal parts of the outfit, such as the switch-table, couch, screening stand, tube stand, and particularly the tube box and handles controlling the movements and diaphragm, should be efficiently earthed. For this purpose a flexible cable is preferable to a rigid wire, which may break or become disconnected. The earth wire should be connected to a water-supply pipe, a drain pipe, or an earthing plate. Wooden floors are safer than concrete for the operator. Concrete should be covered with some suitable material such as wood or thick linoleum. Rubber-soled shoes may prevent a nasty accident.
2. When operating X-ray tubes there should be no slack wires ; all connections should be taut and kept so by a spring.
3. Whenever possible use heavily insulated wires, but even these should always be treated with the same precaution as a bare wire, as the insulation deteriorates in the course of time.

4. All connecting wires and high-tension apparatus must be out of easy reach or guarded so that assistants or patients cannot inadvertently touch them.
5. It is most important that overhead wires should be examined from time to time, and precaution should be taken so that a live wire cannot fall on the patient or operator. With this end in view, it is a good plan to place across the X-ray room several bare wires connected to earth and at right angles and below the high-tension overhead wires so that should one of these break it is brought into contact with an earthed wire.
6. Periodically examine all wires leading from the high-tension apparatus to the overhead high-tension cables, and if necessary duplicate the method of fixing.
7. Great care should be taken that all fuses carry only the maximum current required by the apparatus, so that any overload or earth leakage will immediately blow the fuse.
8. When using the Coolidge tube installation where the metal extremities of the tube may be close to the patient it is desirable to provide a cover of metallic gauze, which is connected to earth so that an involuntary movement may not cause the patient to receive a spark. All metal applicators should also be earthed. Sandbags will be found useful for checking the involuntary movement of patients.
9. In those X-ray rooms which are without a water supply, a special earth plate should be fixed in the ground and an earth wire run round the room so that several earth connections can be easily made.

10. Avoid an arrangement which allows of two pieces of apparatus being simultaneously connected to one high-tension source.
11. Never touch the high-tension trolley rods without first shutting off the current.
12. Do not instal the apparatus in a room so small that it becomes dangerous to move about.
13. Always have a colleague or assistant, if possible, who is familiar with the position of the main switch.
14. When examining and testing an installation do not be satisfied with merely shutting off the main switch on the apparatus, but also switch off at the main supply.

    Apart from the above suggestions great care must be exercised in working because it is impossible to foresee every contingency, and accidents may occur which are not provided for in the above notes.

Workers are reminded that the above precautions only refer to high-tension currents, and that, in addition, there is constant danger from primary and secondary radiations unless there is adequate protection. The occupants of a room above or below the X-ray room may be unwittingly subjected to radiation unless proper steps are taken. The X-ray tube should be completely surrounded by lead sheet, not less than 2 mm. thick (preferably more) leaving only the smallest necessary aperture for the beam of rays utilised to emerge.

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